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THE EXAMINATION AND TREATMENT OF INDUSTRIAL MAGNESIUM FOUNDRY WASTES

BY

ODEN CASS GARST

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

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METALLURGICAL ENGINEER

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Professor of Metallurgical Engineering.

THE EXAMINATION AND TREATMENT OF INDUSTRIAL MAGNESIUM FOUNDRY WASTES 1/

By Oden Cass Garst 2/

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1/ Reprinted from Bureau of Mines Report of Investigation 3860.

2/ Engineer-in-Charge, Waste Metals Projects, U. S. Bureau of Mines, Eastern Experiment Station, College Park, Maryland.

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PREFACE

The light weight and relatively high strength per unit weight of certain magnesium alloys have interested designing engineers for many years. Even though magnesium possesses certain very desirable physical and metallurgical qualities, the progress of the technologic development of the use of this metal has been slow. At the start of the global war, however, the demand for magnesium increased greatly because of the need for its utilization in aircraft for war. This demand was occasioned because it was desired to manufacture the lightest possible heavier-than-air aircraft so that bomb loads could be heavier or the range of the aircraft could be increased. Simultaneously with the increased use of magnesium, mainly in the form of heat-treated magnesium castings, the generation of magnesium scrap also increased. This increase in scrap generation occurred at a time that the nation needed all of its magnesium production for highly essential and critical war materiel. In some foundries these wastes amounted to as much as 85 percent of the weight of the finished usuable magnesium castings produced.

The principle forms of magnesium foundry wastes not recovered by industry are fine dusts, such as, sawdust, rotary filings and grindings, and the melting- and refining-pot drosses. The Bureau of Mines has studied waste generation and has developed processes for the treatment of drosses for the recovery of secondary ingot metal and has also developed processes for the mechanical beneficiation of fine dusts. The studies on fine dusts were continued until suitable melting methods for the recovery of ingot metal, approximately meeting the applicable specifications, were developed. Magnesium sawdust was mechanically beneficiated by either electrostatic

or preferably by treatment on an air table. This ore-dressing treatment removed the sand normally found in the dust and generated a product that could be melted easily. Subsequent melting of this beneficiated sawdust recovered as cast ingot approximately 90 percent of the magnesium alloy originally in the dirty sawdust. Magnesium dross was treated by grinding, screening, and washing methods that generated metallic nodules suitable for charging to a melting pot for the recovery of ingot metal. The nonmetallics removed by the grinding and sizing operations can possibly be utilized in fertilizers for their potash and magnesia content.

Recommendations are made for improved melting methods for magnesium sawdust that increase greatly the yield on melting. A recommendation that finer dusts, such as, magnesium grindings should be destroyed soon after generation, in accordance with the present magnesium foundry practice, is also made.

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FOREWORD

The light weight and relatively high strength per unit weight of certain magnesium alloys have interested designing engineers for many years. Ever since the noted investigator, Mr. R. Bunsen,5/ first produced the element by electrolysis of the fused chloride in 1852, the utilization of the metal in respect to its low density has been considered. The element is widely distributed over the earth's surface in high-grade, as well as low-grade deposits; it occupies the eighth place in the list of elements arranged in order of their decreasing abundance as there is 2.24 percent magnesium in the earth's lithosphere. Even though the element is distributed widely in oxide, hydroxide, carbonate, silicate, and phosphate minerals and also in soluble sulfate and chloride salts in sea water and spring water, as well as being an indispensable constituent of plants and animals, the technology of magnesium was slow in development. This slowness of development was first caused by confusion on the part of the several investigators who at one time thought that magnesia, magnesite, magnetite, and the pyrolusite-type manganese ores were compounds of the same metal. At one time the metal that we now know as manganese was called magnesium, and magnesium was called either magnium or talcium. In addition to this confusion the extremely high activity of the metal, especially at higher temperatures, created obstacles that are still difficult to solve; these difficulties were at first almost insurmountable, with the limited knowledge of the day.

5/ Bunsen, R.; "Darstellung des Magnesiums auf Elektrolytischen Wegem"; Justus Liebig's Annalen der Chemie, Vol. 82, p. 137, 1852.

With the advance of science in all branches, methods for the production of magnesium were developed. The methods first used for producing the element were: (1) reduction of magnesium salts with alkali metals; A. B. Busy 4/ first prepared magnesium by potassium-vapor reduction of the fused chloride at "red-hot" temperatures, (2) electrolysis of aqueous solutions of magnesium salts, and (3) electrolysis of fused magnesium salts. The first trials at magnesium production by the carbothermal reduction of magnesia were failures as sufficient thermodynamic knowledge concerning the reversibility of the reaction between magnesia and carbon was not at hand. As the igneous electrolytic method for making the element was more easily controlled than the others and yielded more metal per unit of energy, considerable work was expended on the improvement of this process. The work in this field was parallel to the work on the electroreduction of aluminum and the alkali metals. For several years the entire magnesium industry was dependent on this igneous electrolysis process for all the supply of the metal, but as demand for the metal increased and as more scientific knowledge was available, other processes were developed. Today magnesium is produced by: the electrolysis of molten magnesium chloride electrolytes, the carbothermal reduction of magnesia in arc furnaces followed by shock cooling of the furnace gases by a cold inert atmosphere, and the silicothermal reduction of calcined dolomite in stainless steel retorts.

The demands for light-weight heavier-than-air aircraft for use in the armies during the second world war stimulated magnesium production.

4/ Mellor, J. W.; "A Comprehensive Treatise on Inorganic and Theoretical Chemistry", Volume 4, P. 264; Longmans, Green and Co., Ltd., 1929, 1074 pp.

Magnesium was used in aircraft in the form of sand and permanent mold castings, die castings, forgings, extrusion, and plate, sheet and strip. Additional large quantities of metal were used in incendiaries and pyrotechnics. During this war period the production of magnesium increased from 3,360 short tons in 1939 to a maximum of 183,884 short tons in 1943. The peak wartime capacity attained in 1943 was 293,000 short tons per year.

Considerably more magnesium alloys were used structurally in the form of heat-treated sand-castings than in other fabricated forms. In order to make satisfactory magnesium sand-castings it is necessary to melt 7 to 8 pounds of alloy and to pour 5 to 7 pounds of alloy per pound of metal in the finished casting. This large ratio between processed metal weight and finished casting weight is necessary because metal must be left in both the melting and refining pots so that dross inclusions will not be poured into the mold and also because the microshrinkage characteristics of magnesium require the use of large risers, feeders, sprues, and gates if a sound high-strength casting is to be obtained. Because of the large quantities of metal involved in each casting and because both the metal and the melting flux have approximately equal densities there is generated a large proportion of scrap during the fabrication of sand-castings. This scrap takes the form of sawings, filings, sprues, gates, risers, butts, flashings, drippings, grinding dust, and pot-sludges and skimmings. A large amount of scrap is generated by even a well-managed foundry with a long backlog of magnesium experience. At the first of the war period it was necessary to increase greatly the nation's magnesium sand-casting capacity by converting certain nonessential ferrous foundries and other plants to the production of magnesium aircraft parts. The introduction into the industry of inexperienced operators added to the already large proportion of scrap to acceptable

production, and this increase was further intensified by the necessity of hiring magnesium foundry labor that had had no previous hot-metal experience.

The excessive quantities of magnesium scrap were being generated at a time when the nation needed a maximum utilization of magnesium metal so that the aircraft program necessary for proper prosecution of the war would not be delayed. The producers of castings and primary- and secondary-ingot, as well as government officials, were concerned. Some work on minimizing scrap generation was done in most foundries and some of the larger foundries and secondary smelters did preliminary work on the recovery of magnesium from scrap. A report on scrap recovery activities of the Dow Chemical Company was presented by Mr. C. E. Nelson 5/ at a Secondary Metals Symposium of the American Institute of Mining and Metallurgical Engineers. Inasmuch as the primary- and secondary-ingot producers and sand-casters were concerned principally with maintaining their production schedules it was not possible for them to develop completely all the necessary reclamation methods. This work on recovery of magnesium from foundry wastes has been completed by the Bureau of Mines. Industry had developed satisfactory methods for the recovery of heavy scrap but had not been able to spend sufficient time for the recovery of light scrap, such as sawings and dust, or for the recovery of metal from melting- and refining-pot drosses. Consequently, the Bureau's activities have been confined to the examination and treatment of dust and drosses. Filings may be processed similarly to sawdust if kept dry. If wet, filings should be discarded and destroyed.

5/ C. E. Nelson; "Secondary Magnesium"; Metals Technology, Vol. 10, pp. 77-84, 1943.

Because magnesium is so active that the finely divided metal has been used as "flash powder" and in pyrotechnics, and because inexperienced operators have caused disasterous magnesium fires, an extreme case of nervousness was developed concerning the dangers of processing magnesium scrap. In general, there is no danger involved in the handling of magnesium scrap if it is kept dry. However, wet magnesium scrap reacts with water generating hydrogen, which may be ignited easily and act as a "fuse", igniting the magnesium. For this reason magnesium scrap should be kept perfectly dry at all times. Finely-divided water-wet magnesium should be destroyed immediately and heavy water-wet scrap should be dried cautiously.

TREATMENT OF MELTING POT DROSSES

Preliminary Small Scale Tests

Preliminary examination of magnesium dross had indicated a "metallics" content of 50-60 percent. In order to have comparative data on methods of effecting the metallic-nonmetallics separation, barrel of magnesium dross representing waste products of "rubbings" and "skimmings from the melting pots before and after puddling" was obtained from the Maryland Sanitary Manufacturing Corporation's Baltimore foundry for beneficiation tests for the separation of the magnesium metal from the slag by ore dressing methods. Small scale dry-grinding and screening tests were made on this sample.

Petrographic analysis showed the magnesium metal to be sufficiently free at minus 10-mesh to permit the separation of the metallics and nonmetallics.

A sample crushed to minus 2 inches was screened on a 28-mesh screen. The minus 28-mesh was rejected as nonmetallics and the plus 28-mesh material was ground for 30 minutes in a steel ball mill with a charge of iron balls. The ground material was screened on 10-mesh and 28-mesh screens. The minus 28-mesh material was combined with the minus 28-mesh before grinding to make the total nonmetallic fraction. The plus 10-mesh and plus 28-mesh fractions were the metal. Results of this test are shown in table 1.

The same procedure as in the preceding test was employed on another sample except that the minus 10-mesh was rejected as nonmetallics and the plus 10-mesh was ground. The ground material was screened on a 10-mesh and 28-mesh screens; the minus 28-mesh was combined with the minus 10-mesh nonmetal to make the nonmetallic fraction. The results of this test are also shown in table 1.

Another sample, crushed to minus 2-inch, was ground for 30 minutes without any previous screening to remove the free nonmetallic material. The ground pulp was screened on 10-mesh and 28-mesh screens, the minus 28-mesh being the nonmetallic and the plus 10-mesh and plus 28-mesh the metal. The results of this test are also shown in table 1.

The chemical and spectrographic analyses listed in table 1 do not composite to 100 percent because no determinations were made that would differentiate between metallic magnesium, magnesium nitride, magnesium carbide, and magnesium oxide. Products classified as plus 10- and plus 28-mesh metallics were not 100 percent metal but are mixture of metal, oxide, nitride, and carbide. This mechanical mixture was intimately interlocked and the metal content could not be freed completely by grinding and screening. In this paper the term "metallics" is used to designate the partially cleaned metallic-nonmetallic nodules that are liberated by grinding and screening, while the term metal is used to describe the product made by melting and casting the metallics.

The results of these tests indicate that dry-grinding in ball mills would not yield a metallic product containing over 65 percent magnesium. The grinding action appeared to imbed the nonmetallic material in the particles of metal and extending the grinding period would not separate them. It is believed that wet grinding or scrubbing will be required to obtain clean metallics.

Final Pilot Plant Scale Tests.

The previously reported preliminary examination of melting and refining pot dross had indicated a "metallics" content of 30-40 percent. Four 55-gallon steel drums of dross of three distinct types; (1) "rubbings" from the

Table 1. - Results of Small Scale Dry Grinding Tests on Magnesium Dross

Part A - Tests on Plus 28-mesh Mill Feed

Product	Fraction Weight	Partial Analyses												
		Chemical											Spectrographic	
	%	Mg %	Al %	Fe %	SiO_2 %	Mn %	CaF_2 %	Cl %	K_2O %	Ca %	Na %	Ni %	Zn %	Cu %
+10 metallics	26.3	62.4	5.10	0.52	0.40	.14	---	---	---	---	---	0.25	1.0-5.0	.1-.5
+28 metallics	6.5	64.8	5.50	1.10	1.20	.17	---	---	---	---	---	0.25	0.1-0.5	.05-.1
-28 non-metallics	67.2	29.3	2.00	1.48	14.50	---	2.25	19.0	6.8	3.5	0.35	---	---	---
Composite	100.0	40.3	5.00	1.20	9.94	---	---	---	---	---	---	---	---	---

Product	Fraction Weight %	Distribution			
		Mg %	Al %	Fe %	SiO_2 %
+10 metallics	26.3	40.7	44.6	11.3	1.0
+28 metallics	6.5	10.4	11.3	6.0	0.8
-28 nonmetallics	67.2	48.9	44.1	82.7	98.2
Composite	100.0	100.0	100.0	100.0	100.0

Table 1. - Results of Small Scale Dry Grinding Tests on Magnesium Dross.

Part B - Dry Grinding in Ball Mill, Plus 10-mesh Feed.

Product	Fraction Weight	Partial Analyses												
		Chemical											Spectrographic	
	%	Mg %	Al %	Fe %	SiO_2 %	Mn %	CaF_2 %	Cl %	K_2O %	Ca %	Na %	Ni %	Zn %	Cu %
+10 metallics	26.5	61.6	5.00	0.62	0.45	.17	---	---	---	---	---	0.27	1.0-5.0	.1-.5
+28 metallics	4.7	62.7	4.26	0.75	0.60	.16	---	---	---	---	---	0.33	0.5-1.0	.05-.1
Nonmetallics	69.0	27.6	1.99	1.45	14.80	---	---	---	---	---	---	---	---	---
Composite	100.0	38.2	2.90	1.20	10.35	---	---	---	---	---	---	---	---	---

Product	Fraction Weight %	Distribution			
		Mg %	Al %	Fe %	SiO_2 %
+10 metallics	26.5	42.4	45.0	13.5	1.0
+28 metallics	4.7	7.7	6.9	2.9	0.3
Nonmetallics	69.0	59.9	48.1	83.6	98.7
Composite	100.0	100.0	100.0	100.0	100.0

Table 1. - Results of Small Scale Dry Grinding Tests on Magnesium Dross.

Part C - Dry Grinding in Ball Mill, Minus 2-inch Feed

Product	Fraction Weight	Partial Analyses												
		Chemical											Spectrographic	
	%	Mg %	Al %	Fe %	SiO_2 %	Mn %	CaF_2 %	Cl %	K_2O %	Ca %	Na %	Ni %	Zn %	Cu %
+10 metallics	27.2	62.6	5.20	0.62	0.40	.16	---	---	---	---	---	0.25	1.0-5.0	.1-.5
+28 metallics	7.3	62.7	5.00	0.70	0.64	.16	---	---	---	---	---	0.30	0.5-1.0	.05-.1
-28 non-metallics	65.5	29.3	2.00	1.78	12.40	---	2.25	19.0	6.8	3.5	0.34	---	---	---
Composite	100.0	40.8	3.10	1.38	8.28	---	---	---	---	---	---	---	---	---

Product	Fraction Weight	Distribution			
	%	Mg %	Al %	Fe %	SiO_2 %
+10 metallics	27.2	41.7	45.5	11.6	1.4
+28 metallics	7.3	11.2	11.7	3.6	0.5
-28 non-metallics	65.5	47.1	42.8	84.8	98.1
Composite	100.0	100.0	100.0	100.0	100.0

refining pots, (2) "premelt dross" drom the primary melting pots, and (3) "skimmings before and after puddling" from the primary melting pots, were received for further tests on metal recovery by the grinding and sizing method. Because the disposal of large quantities of saturated chloride brine would be a considerable problem and because it is possible to return the higher grade nonmetallics to the melting pots as low-grade flux, a dry-grinding procedure was chosen in preference to a wet-grinding one.

Grinding and Screening

Each of the three different types of dross was ground separately in the 3 x 3 foot ball mill of the Denver Equipment Company with a ball charge of 1,800 pounds. The mill was operated batch fashion. After each charge was ground for a period of 20 minutes the charge and balls were removed, caked "nonmetallics" adhered to the walls of the mill were not cleaned off between runs. Balls were separated from the ground dross by screening and handsorting, and then returned to the mill. The dross was sized by screening on 10- and 20-mesh screens. The data obtained from these experiments are listed in table 2, and the analyses of the products are listed in table 3. Because it was not practicable to take a fully representative sample of the plus 10-mesh "metallics" no analyses of this material were made.

Cleaning Metallic Nodules

The metallic particles were coated with a layer of flux salts and oxides not removed by dry grinding and screening. In addition, cracks and holes in the rough shot metal were filled with salts and oxides. Removal of these closely associated nonmetallics from the metal should decrease the flux consumption on melting the particles.

Table 2. - Dry Grinding Tests on Maryland Sanitary Magnesium Dross.

Product	"Rubbings"						"Premelt Dross"		"Skimmings before & After Paddling"	
	Charge No. 1		Charge No. 2		Total		Charge No. 3		Charge No. 4	
	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.		Lbs.	%
To mill	268	100.00	472	100.00	740	100.00	406	100.00	418	100.00
+10 metallics	57	21.27	135	28.60	192	25.96	262	64.53	95	22.73
-10+20 metallics	19	7.09	37	7.84	56	7.57	24	5.91	41	9.81
-20 nonmetallics	143	53.36	282	59.76	425	57.43	120	29.56	270	64.59
"Loss" nonmetallics	49	18.28	18	3.81	67	9.05	---	---	12	2.87
Total metallics recovered	76	28.36	172	36.44	248	33.52	286	70.44	136	32.54

Table 3. - Partial Analyses of Metallics and Nonmetallics Produced by Grinding and Screening Magnesium Drosses

Determined	Chemical Analyses					
	-10-,+20-mesh metallics			-20-mesh nonmetallics		
	Rubbings %	Premelt %	Skimmings %	Rubbings %	Premelt %	Skimmings %
Mg	55.3	49.2	56.1	33.4	33.2	36.7
Al	3.97	3.85	4.71	1.92	2.4	2.8
Zn	1.58	1.40	1.46	---	---	---
Mn	0.09	0.25	0.11	---	---	---
Cu	0.01	0.01	0.01	---	---	---
SiO_2	0.71	0.95	0.51	---	---	---
Fe	1.55	2.22	1.96	---	---	---
Ni	0.01	0.01	0.01	---	---	---
CaF_2	2.46	1.72	2.15	3.92	2.91	2.29
Cl	---	---	---	18.8	16.6	13.9
K_2O	---	---	---	7.7	10.8	4.6
Ca	---	---	---	3.87	2.15	2.93
Na	---	---	---	0.44	0.46	0.21

Two methods of cleaning the plus 10-mesh metallics, i. e., (1) abrasive dry grinding, and (2) water leaching, were tested. In each test on the abrasive dry-grinding method, 500 grams of plus 10-mesh metallics were charged to an Abbe pebble mill one-third full of the abrasive to be used. Data on tests in which the grinding medium was sand, 3/16 inch steel shot, or 1/32 inch by 1/4 inch dished steel slugs, are listed in table 4. In addition to these tests, one test was run in which the metallics were tumbled in a mill with sawdust. The protruding surfaces of metal were polished but sawdust did not clean occluded nonmetallics from the shot metal. In the tests tabulated, the abrasive and finely ground nonmetallics were removed from the metal by screening or by a magnetic method.

Table 4. - Cleaning plus 10-mesh Magnesium Dross Metallics by Abrasive Dry Grinding

Abrasive	Metallics recovered per 500 grams Plus 10-mesh Metallics	Nonmetallics Removed.
	Grams	Percent
Sand	470	6.0
Shot	481	3.1
Slugs	468	6.2

Because the removal of approximately 6 percent nonmetal was not deemed to be sufficient cleaning, a test of water leaching to remove excess nonmetallics was conducted. In this test 25 kilograms of plus 10-mesh metallics were agitated with water in a flotation conditioner. Nonmetallics were taken off, both as slime and as brine, by continuously washing during the agitation period. The clean metal after leaching seemed to be free of all occluded salts and oxides. After the leaching operation the metal was dried in the sun; during the drying operation a

surface coating of magnesium oxide was formed on the particles. This coating was removed by grinding with sharp sand and screening. Data on this test are given in table 5. These data show a weight loss of 17 percent nonmetallics; the product was thought to represent the cleanest metallic fraction that could be obtained from the plus 10-mesh metallic fraction of magnesium dross by mechanical methods.

Table 5. - Cleaning Plus 10-mesh Dross Metallics by Leaching, Drying, and Abrading

Product	Weight	
	Kilograms	Percent
Plus 10-mesh metallics	25.00	100.00
Leached and dried metallics	21.62	86.48
Sand abraded leached metallics	20.76	83.04
Removed by process	4.24	16.96

Preliminary cleaning tests on the minus 10-, plus 20-mesh metallics fraction showed that a maximum of 55 percent nonmetallics could be removed by grinding with a planetary pulverizer and rescreening on a 20-mesh sieve. This relatively large proportion of oxides and salts seemingly interfered with efficient metal collection on melting by producing a thick gummy flux layer. Three methods of cleaning the minus 10-mesh metallics, (1) tumbling with sand and screening, (2) one pass through a 24-inch diameter roll crusher and screening, and (3) four passes through an 8-inch diameter roll crusher and screening, were tested. The data on these experiments are listed in table 6.

Melting Tests on Metallics

Melting tests were carefully conducted on these plus 10-mesh metallics, plus 10-mesh cleaned metallics, minus 10-, plus 20-mesh metallics,

and minus 10-, plus 20-mesh cleaned metallics. The pasty process of melting was used in order to minimize the consumption of flux and the loss of metal by burning on melting. In these tests the dross metallics were heated to a temperature near the melting point and were then worked into a pasty mush.

Table 6. - Cleaning Experiments on Minus 10-, Plus 20-mesh Metallics.

Test Number	Metallics Cleaned	Metallics Recovered	Nonmetallics Recovered	
	Grams	Grams	Grams	Percent
1. Sand tumbling	15,500	14,000	1,500	9.68
2. Grinding 24" rolls	14,000	12,000	2,000	14.29
3. Grinding 8" rolls				
Pass No. 1	12,000	9,650	2,400	20.00
Pass No. 2	9,600	7,250	2,350	19.58
Pass No. 3	7,250	6,200	1,050	8.75
Pass No. 4	6,200	5,500	700	5,83
Total	12,000	5,500	6,500	54.17

After the melting pot was full of metal, the temperature was raised until the metal became thoroughly liquid; a dry dross was skimmed, and the metal was poured into ingot. The quantity of flux used was just sufficient to prevent the charge from burning.

Data on these experiments are listed in table 7. These data prove that it is possible to recover from the refining pots, by dry grinding and screening followed by melting, a minimum of 274 pounds of magnesium alloy ingot per short ton of "rubbings" dross. If the plus 10-mesh metallics are cleaned by water washing before melting, and if the

Table 7. - Melting Tests on Magnesium Dross Metallics

Metallics Charged	Plus 10-mesh		Plus 10-mesh Cleaned	-10 plus 20 Mesh	-10 plus 20-mesh Cleaned	Total
Test number	1	2	3	4	5	
Charge weight - grams	14,800	16,075	14,620	8,920	2,720	
Flux used - Dow No.	310	310	310	310	230	
Flux consumed - grams	1,170	1,140	1,025	900	610	
Ingot weight - grams	7,610	8,280	9,480	590	1,440	
Ingot, % of charge weight	51.5	51.5	64.8	4.37	52.9	
Flux, % of charge weight	7.9	7.1	7.0	10.09	22.4	
Pounds ingot per 2,000 lbs.						
Rubbings	266	267	279	6.62	36.7	315.7
Skimmings	253	254	245	8.57	47.6	292.6
Premelt	662	663	695	5.17	28.7	725.7
Pounds flux per 2,000 lbs.						
Rubbings	41	37	30	15.3	15.6	45.6
Skimmings	36	32	26	10.8	20.2	46.6
Premelt	101	92	75	11.9	12.2	87.8

minus 10-, plus 20-mesh metallics are cleaned by regrinding and screening, a minimum of 316 pounds of ingot can be recovered.

The additional operations of water washing, drying, and abrading, on the indicated 518 pounds of minus 10-mesh metallics, result in the recovery of 12 pounds more of alloy and in the saving of 9 pounds of flux per short ton of dross; and the additional operations of regrinding and screening, on 161 pounds of minus 10-, plus 20-mesh metallics permit the recovery of 30 more pounds of alloy and the saving of 10 pounds of flux.

The flowsheet of figure 1 shows diagramatically the steps followed in the pilot plant treatment of magnesium dross. Weights of varying intermediates that are shown on this flowsheet are calculated for the treatment of "rubbings" from the refining pots. The product weights for the treatments of the other forms of magnesium dross are listed in tables 2, 5, 6 and 7, and are recapitulated in table 8.

Cost estimates based on 1 ton of "rubbings" are listed in table 9. These estimates are indicative of considerable profit for the process of recovering metal from dross. Profit may be increased by sale of nonmetallics to a fertilizer company.

The listing of table 9 indicates the possible profit realizable from the recovery of ingot metal from magnesium dross as "Gross Profit", because no allowances were made in the estimate for; (1) purchase price of raw dross, (2) freight on raw dross and on ingot metal, (3) plant overhead, (4) capital cost and depreciation of equipment, and (5) possible lowering of selling price of ingot metal caused by necessity for blending and/or degrading to a less valuable alloy. No estimates were made on these five items because they would be different for each dross treatment plant and for each source of dross. The cost estimate, consequently, covers only the actual direct

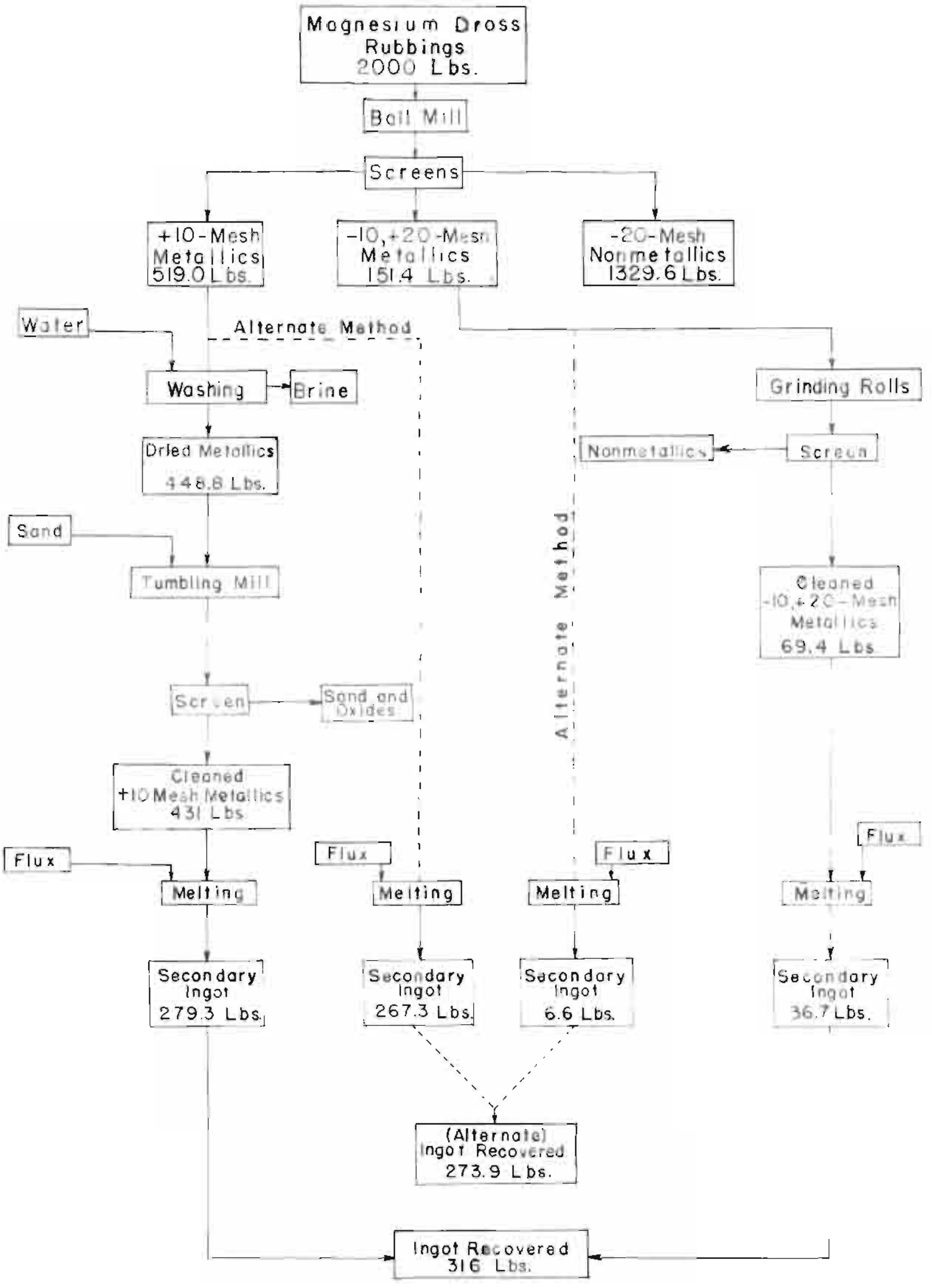


Figure 1—FLOW SHEET USED FOR THE PILOT PLANT TREATMENT OF MAGNESIUM DROSSES

Table 8. - Weights of Products Expected in the Treatment of Magnesium Drosses.

Product	Dross Type Treated		
	"Rubbings" Pounds	"Premelt" Pounds	"Skimmings" Pounds
Raw Dross	2000	2000	2000
Plus 10-mesh metallics	519	1290.6	454.6
Plus 20-mesh metallics	151.4	118.2	196.2
Minus 10-mesh nonmetallics	1329.6	591.2	1349.2
Plus 10-mesh dried metallics	448.8	1116.1	393.1
Plus 10-mesh cleaned metallics	431	1071.7	377.5
Secondary ingot (alternate method)	267.3	664.7	234.1
Secondary ingot	279.3	694.5	244.6
Plus 20-mesh cleaned metallics	69.4	54.2	89.9
Secondary ingot (alternate method)	6.6	5.2	8.6
Secondary ingot	36.7	28.7	47.6
Ingot recovered (alternate method)	273.9	669.9	242.7
Ingot recovered	316	723.2	292.2

operating cost, and the net profit realized from the operation would be considerably less than the tabulated gross profit. A probable value for the estimated "Net Profit" would be in the range of $15 to $20 per ton of raw dross treated for the recovery of approximately 300 pounds of ingot metal.

Table 9. - Cost Estimates on Recovery of Secondary Magnesium Ingot from Dross Based on One Ton of Rubbings

Debits		Credits	
Grinding and mill cleaning	$3.00	Ingot metal, 315 lbs. at $.20	$63.00
Screening	0.25		
Leaching, drying and abrading	1.50		
Regrinding and screening	1.00		
Melting and casting	6.00		
Flux, 46 lbs. at 7¢ per lb.	3.22		
	$13.97		

Gross Profit per ton "Rubbings" $49.03

Analyses of cast metal recovered from magnesium dross are compared with the applicable Aeronautical Material Specification in table 10. The high iron found in the recovered ingot would be lowered by refining by standard plant methods, using a flux containing manganese chloride.

Table 10. - Analyses of Cast Metal Recovered from Magnesium Dross Compared with A.M.S. 4420

Determined	Recovered Metal Percent	Recovered Metal Percent	A.M.S. 4420 Percent
Al	5.55	5.44	5.3 to 6.7
Zn	2.93	3.06	2.5 to 3.5
Mg	90.80	91.00	remainder
Mn	0.19	0.20	0.15 minimum
Cu	0.06	0.06	0.05 maximum
Ni	nil	nil	0.01 maximum
Si	0.06	0.12	0.30 maximum
Fe	0.32	0.15	
Others	----	----	0.30 maximum
Total	99.71	100.03	

TREATMENT OF FOUNDRY DUSTS

Considerable metallic dust is generated during the fabrication and cleaning of magnesium sand-castings. These metallic dusts are formed principally in the sawing, filing, and grinding operations, and because of their small size these dusts are generally regarded as a distinct hazard. In most foundries the dusts are collected in steel drums and burned soon after generation; development of reclamation methods applicable to the production of ingots for reuse would be advantageous economically because of direct saving of metal and the elimination of labor necessary for the burning operation.

Magnesium Sawdust

General

Magnesium sawdust is generated by the high-speed, coarse-tooth band saw that is used to trim off gates and risers from the finished casting. The high-speed sawing operation jars off any foundry sand that adheres to the casting. The high-speed sawing operation also fuses the tips of the saw-tooth points and some spherical iron particles are generated. Contamination with iron shot from the shot-blasting operation also occurs. These two impurities, sand and iron shot, fall to the floor and become mixed with the magnesium alloy chips. Periodic sweeping removes the contaminated waste. Because of the fire hazard attributable to both small particle size and reaction between silica and magnesium, the standard plant melting-practice is not applicable. Consequently, soon after generation, magnesium sawdust is destroyed.

Preliminary Beneficiation Tests on Grab Samples

General

The chemical and physical characteristics of a grab sample of magnesium sawdust are listed in table 11. The large quantity of sand causes considerable burning during attempts to conduct the melting according to standard melting methods. The total iron content of the sawdust is considerably higher than the amount allowed by the controlling specification - Aeronautical Material Specification 4420.

Preliminary examination of a small grab sample indicated the presence of a large proportion of iron spheroids. By cleaning with a Davis Tube separator, 7.2 percent by weight of these iron particles were removed and a nonmagnetic fraction produced that analyzed 0.08 percent iron. The usual form of low-intensity magnetic separator could not duplicate these results; the nonmagnetic fraction contained considerably more iron. Treatment on both high- and low-intensity machines, however, produced a nonmagnetic fraction that analyzed 0.05 percent iron. Subsequent cleaning of this fraction on an electrostatic machine, with negative electrodes, reduced the hydrochloric acid insoluble to 0.3 percent. This cleaned fraction contained over 99 percent "H" alloy. No conclusive data can be tabulated on these tests because the grab sample was probably not representative of the plant waste regularly produced.

Magnetic and Electrostatic Separation

A subsequent grab sample of approximately 100 pounds of sawdust collected was probably representative of normal plant practice at the Maryland Sanitary Manufacturing Corporation; its chemical analysis listed in table 11 indicated a material similar to the sample previously examined. Qualitative confirmation of this listed analysis was made by combined petrographic

Table 11. - Chemical and Screen Analysis of Magnesium Sawdust from the Maryland Sanitary Manufacturing Corporation.

Mesh Tyler	Screen Analysis Percent	Cumulative Percent
+8	3.55	3.55
-8-,+20	16.59	20.12
-20-,+65	63.86	83.98
-65-,+100	7.17	91.15
-100-,+150	3.66	94.81
-150-,+200	2.07	96.88
-200-,	3.12	100.00

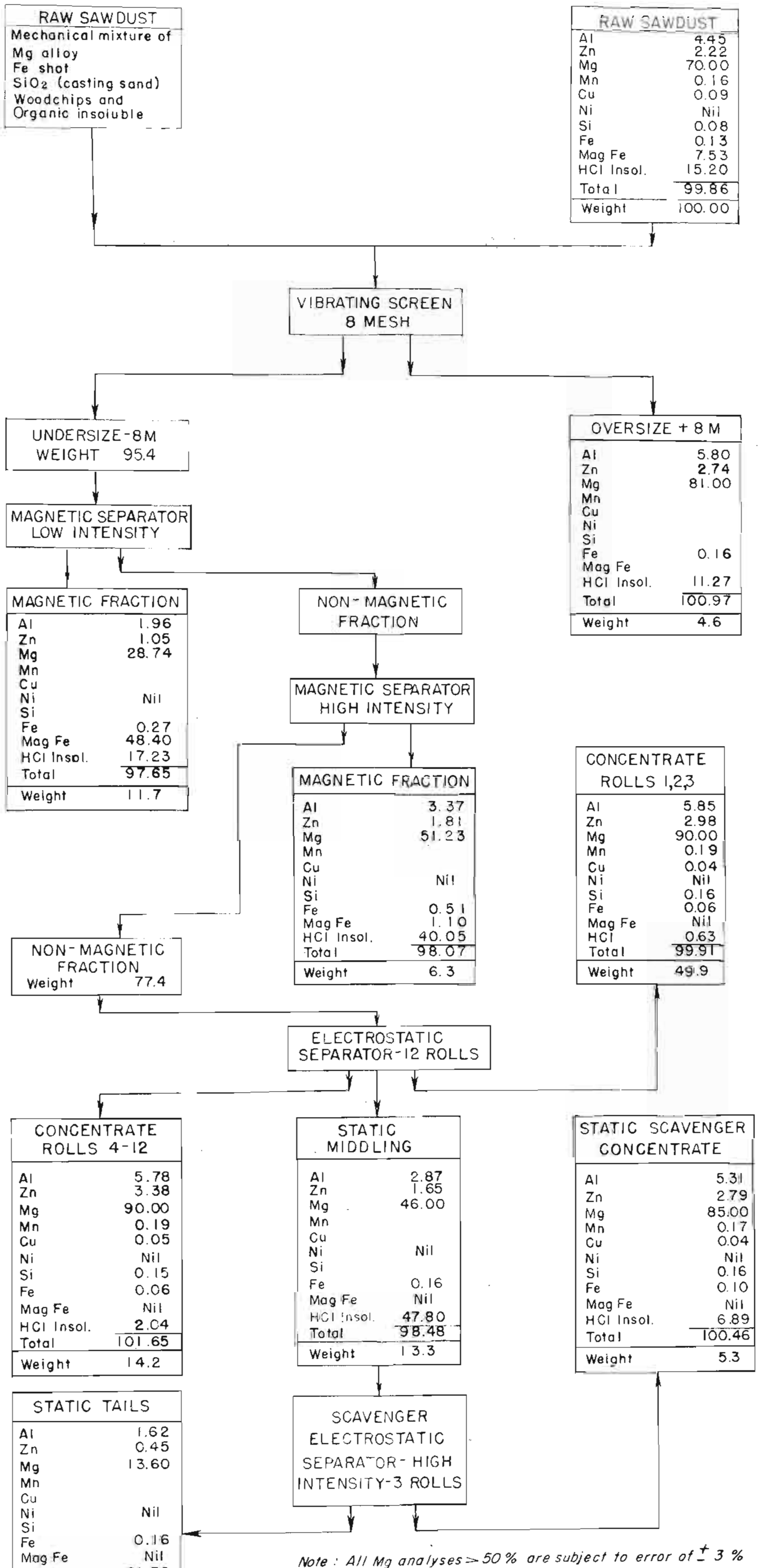
Chemical Analysis Determined	Percent
Al	4.45
Zn	2.22
Mg	70.00
Mn	0.16
Cu	0.09
Ni	nil
Si	0.08
Fe	0.12
Magnetic Fe	7.53
Sand	15.20
Total	99.85

and magnetic methods. Spheroids of iron were isolated magnetically and on spectrographic examination they were proved to be composed only of iron, with a trace of manganese; no aluminum zinc, or magnesium could be detected spectrographically. Petrographic examination of the minus 8-mesh nonmagnetic fraction proved it to be a mixture of magnesium alloy and quartz casting sand. No locked grains of alloy and sand were noted.

Because the sawdust was available dry, it was decided to confine the first series of beneficiation experiments to dry rather than to wet methods. Low-intensity and high-intensity magnetic machines were used to remove iron. The resultant quartz-alloy mixture was separated on an electrostatic machine. A flow-sheet of the laboratory operations is shown in figure 2. Statistical data on the operations are given in tables 12 and 13. Large discrepancies in the material balances were noted. These errors were caused undoubtedly by inaccuracies in analyzing the samples that contained iron shot and sand.

A critical screen analysis of the cleaned final product is listed in table 14. This analysis represents the cleanest product made. Sizing the concentrate on a 65-mesh screen, and discarding the 2.04 percent undersize, would eliminate 43 percent of the sand and 12 percent of the iron. This operation would produce a metallic powder, sized between 8-mesh and 65-mesh, that contains only 0.36 percent insoluble matter and 0.05 percent iron. The remaining 99.59 percent would consist of metal that meets the stipulations of Aeronautical Material Specification 4420.

The data presented in tables 12 and 13 and on the flowsheet of figure 2 were used as basic data to compute the weight and the chemical analyses of the unanalyzed intermediate products. The computed and actual chemical analyses were used for calculations to develop a hypothetical plant flowsheet



Note : All Mg analyses > 50 % are subject to error of ± 3 %

Figure 2— FLOWSHEET USED FOR LABORATORY TEST ON BENEFICIATION OF MAGNESIUM SAWDUST.

Table 12. - Statistical Data, Magnetic and Electrostatic Concentration of Magnesium Sawdust from the Maryland Sanitary Manufacturing Corporation.

Product Designation	Fraction	Analyses		Calculated Equivalent	
		HCl Insol.	Total Fe	HCl Insol.	Total Fe
	%	%	%	%	%
Heads, raw sawdust	100.00	15.20	7.66	15.20	7.66
+8-mesh, not beneficiated	4.6	11.27	0.16	0.52	0.0078
-8-mesh, low-intensity magnetic	11.7	17.23	48.67	2.02	5.6944
-8-mesh, high-intensity magnetic	6.3	40.05*	1.61*	2.52	0.1014
-8-mesh, static concentrate, rolls 1-3 incl.	49.9	0.65	0.06	0.32	0.0300
-8-mesh, static concentrate, rolls 4-12 incl.	14.2	2.04	0.06	0.29	0.0085
-8-mesh, static middling, rolls 13-15 incl.	5.5	6.89*	0.10*	0.37	0.0053
-8-mesh, static tailing, rolls 13-15 incl.	8.0	81.50	0.16	6.50	0.0181
Composite, raw sawdust	100.00	-----	----	12.54	5.87

Product Designation	Distribution	
	HCl Insol.	Total Fe
	%	%
Heads, raw sawdust	100.00	100.00
+8-mesh, not beneficiated	4.15	0.15
-8-mesh, low-intensity magnetic	16.11	97.02
-8-mesh, high-intensity magnetic	20.10	1.73
-8-mesh, static concentrate, rolls 1-3 incl.	2.55	0.55
-8-mesh, static concentrate, rolls 4-12 incl.	2.31	0.16
-8-mesh, static middling rolls 13-15 incl.	2.95	0.09
-8-mesh, static tailing, rolls 13-15 incl.	51.83	0.32
Composite, raw sawdust	100.00	100.00

* Questionable analyses
** All Mg analyses higher than 50% are subject to error of ± 5%.

Table 13. - Complete Chemical Analyses of Products from Magnetic and Electrostatic Beneficiation of Magnesium Sawdust from the Maryland Sanitary Manufacturing Corporation.

Product	Determined							
	Al %	Zn %	Mg** %	Mn %	Cu %	Ni %	Si %	Fe %
Heads, raw sawdust	4.45	2.22	70.00	0.16	0.09	nil	0.08	0.13
+8-mesh	5.80	2.74	81.00	----	----	---	----	0.16
Low-intensity magnetic	1.96	1.05	28.74	----	----	---	----	0.27
High-intensity magnetic*	3.37	1.81	51.23	----	----	---	----	0.51
Static concentrate, rolls 1-3 incl.	5.85	2.98	90.00	0.19	0.04	nil	0.16	0.06
Static concentrate, rolls 4-12 incl.	5.78	3.38	90.00	0.19	0.05	nil	0.15	0.06
Static middling, rolls 4-12 incl.	2.87	1.65	46.00	----	----	nil	----	0.15
Static scav. cone, rolls 13-15 incl.	5.31	2.79	85.00	0.17	0.04	nil	0.16	0.10
Static tailings, rolls 13-15 incl.*	1.62	0.45	13.60	----	----	---	----	0.16
Composite, raw sawdust	4.65	2.53	75.33	----	----	nil	----	0.13
Recovery on processing	109.0	114.0	107.6	----	----	nil	----	100.0

Product	Determined		
	Magnetic %	HCl Insol. %	Total %
Heads, raw sawdust	7.53	15.20	99.85
+8-mesh	nil	11.27	100.97
Low-intensity magnetic	48.40	17.23	97.65
High-intensity magnetic*	1.10*	40.05	98.07
Static concentrate, rolls 1-3 incl.	nil	0.63	99.91
Static concentrate, rolls 4-12 incl.	nil	2.04	101.65
Static middling, rolls 4-12 incl.	nil	47.80	98.48
Static scav. cone, rolls 13-15 incl.	nil	6.89	100.46
Static tailings, rolls 13-15 incl.*	nil	81.30	97.13
Composite, raw sawdust	5.73	12.54	101.11
Recovery on processing	76.1	82.5	100.0

* Questionable analyses
** All Mg analyses higher than 50% are subject to error of ± 3%.

Table 14. - Screen Analysis of Cleaned Magnesium Sawdust Produced from Wastes from the Maryland Sanitary Manufacturing Corporation.

Product	Screen Size Tyler	Fraction	Analyses		Calculated Equivalent		Distribution	
			Insol.	Fe	Insol.	Fe	Insol.	Fe
		%	%	%	%	%	%	%
Heads	-8-,	100.00	0.63	0.06	0.63	0.06		
	-20	24.75	0.16	0.04	0.04	0.010	8.17	19.73
	-20-,-35	55.13	0.16	0.04	0.09	0.021	18.38	43.52
	-35-,-65	20.09	0.77	0.06	0.15	0.012	50.60	24.45
	-65-,	2.04	10.20	0.30	0.21	0.006	42.85	12.42
Composite	. . . . .	100.00	----	----	0.49	0.049	100.00	100.00

for the treatment of magnesium sawdust. Because the analyses and the material balances on the laboratory tests proved to be inaccurate, several engineering assumptions were necessary before the weights and the analyses of all the products on the plant flowsheet could be calculated. In this series of calculations no special effort was made to composite correctly each element in the magnesium alloy. The various magnesium analyses were chosen as a guide to the weight of magnesium alloy present. Other necessary assumptions in making the many calculations are:

1. The analyses for the raw sawdust, the plus 8-mesh screen fraction, the magnetic fraction from the low-intensity magnetic separator, the concentrate produced on the scavenger electrostatic separator, and the concentrate produced by the first three rolls of the primary electrostatic separator were assumed to be correct.

2. All the residual magnetic iron in the low-intensity, nonmagnetic fraction will be removed in the magnetic fraction from the high-intensity magnetic separator.

3. If the magnetic fraction from the high-intensity magnetic separator is passed over a second low-intensity machine, all the magnetic iron will be concentrated in a low-intensity magnetic fraction, and this magnetic fraction will have the same chemical analysis as the product of the first low-intensity magnetic separator.

4. The operation of electrostatic separation will not in itself cause a gain in the weight of magnesium. The apparent gain in weight shown in table 13 was caused by inaccuracies in several analyses.

5. If the electrostatic concentrate from rolls four to twelve is recirculated back over the electrostatic separator, it will split into

three products: (a) concentrate from rolls one to three inclusive, (b) scavenger concentrate, and (c) static tailing. The magnesium metal content of these three products will be proportioned in the same ratio as in the original products of figure 2.

6. If the scavenger concentrate is recycled back to the primary electrostatic separator it will be split into two products: (a) concentrate from rolls one to three inclusive, and (b) static tailing. The magnesium metal content of these two products will be proportioned in the same ratio as in the original products shown on figure 2.

The results of these engineering computations are presented diagramatically on the flowsheet of figure 3. These calculations indicate that it is possible to treat magnesium sawdust that contains 15.2 percent sand and 7.5 percent magnetic iron, and produce a concentrate that contains 0.63 percent sand and no magnetic iron. The calculated recovery for the hypothetical flowsheet is 86.2 percent.

Additional tests were conducted on the electrostatic separation of magnesium sawdust. For these tests the separator was altered for fireproof operation. All exposed low-voltage high-amperage electrical conductors, such as slip rings, were placed under cover, and helium gas electrical discharge tubes were substituted for the metal electrodes formerly used. A second grab sample of magnesium sawdust was obtained for these tests.

Several adjustments of the electrodes were tried. The results for the best adjustment are summarized in table 15. The products were not as high-grade and recoveries were not as good as those obtained in previous tests. This poorer separation probably resulted from the electrode change and possibly reflected the difference in the head sample treated. The

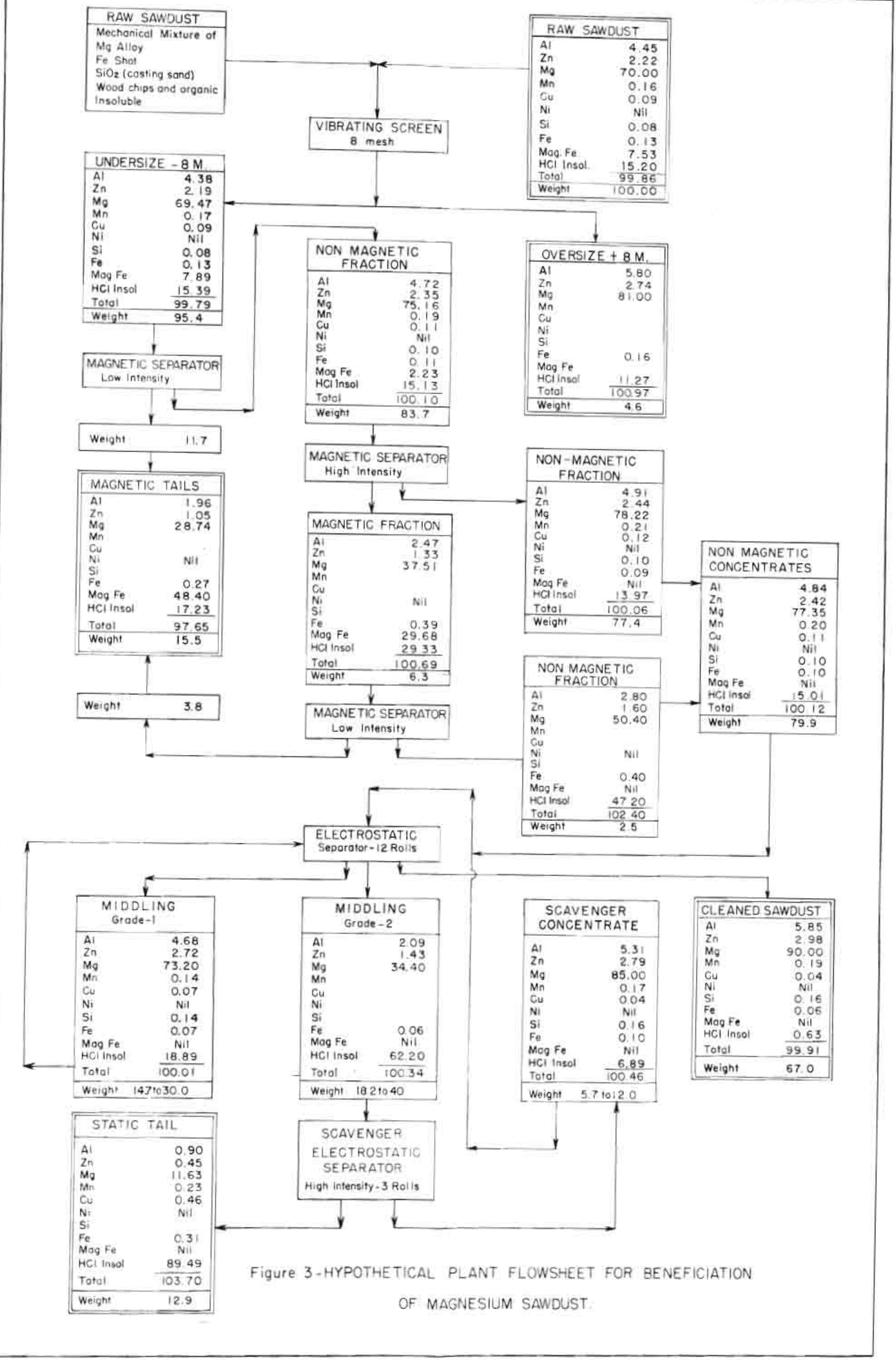


Figure 3 - HYPOTHETICAL PLANT FLOWSHEET FOR BENEFICIATION OF MAGNESIUM SAWDUST.

Table 15. - Electrostatic Separation of Magnesium Sawdust.

Product	Weight	Analyses			Distribution		
		Magnetic	HCl Insol.	HCl Soluble Mg Alloy	Magnetic	HCl Insol.	HCl Soluble. Mg Alloy
	%	%	%	%	%	%	%
1. Conc.	55.0	15.8	1.8	82.4	37.3	7.9	70.6
2. Midds.	12.4	39.1	5.9	55.0	20.8	5.8	10.6
3. Tailings	32.6	29.9	33.3	36.8	41.9	86.3	18.8
Composite	100.0	23.3	12.6	64.1	100.0	100.0	100.0

raw sawdust was passed over a twelve-roll separator, once. Product one is the deflected material from the first six rolls, and product two is the deflected material from the last six rolls. Electrodes consisted of two adjacent, 0.5-inch diameter, helium discharge tubes per roll. The distance between each electrode and roll was approximately 0.5 inch, and the line through the center of the roll and the midpoint of the electrodes was approximately 45° with the horizontal. The electrodes were excited with alternating current and were also raised to a high negative polarity with respect to ground-potential by a direct current source.

Products one and two from the electrostatic test were separated magnetically with the Dings induced roll separator at high- and low-intensities, and a nonmagnetic product was obtained that analyzed 1.4 percent insoluble and 0.05 percent iron. The results of this test are shown in table 16.

The data of tables 15 and 16 indicate a recovery of approximately 95 percent of the magnesium alloy of the raw sawdust in an electrostatic concentrate if the middling and the tailing are circulated in accordance with the flowsheet of figure 3 and a recovery of approximately 90 percent of the magnesium alloy of the static concentrate in a final nonmagnetic concentrate if the high-intensity magnetic fraction be recleaned on a low-intensity machine - also in accordance with the flowsheet of figure 3. These approximations indicate a recovery of 85 percent of the magnesium alloy of the raw sawdust in a final concentrate that contained about 1.5 percent silica, and 0.05 percent iron. These data are considered to be in good agreement with the data on the tests described by figures 2 and 3. The higher silica content of the final concentrate of this second test was probably caused by the more tortuous chip shape of the magnesium alloy.

Table 16. - Magnetic Separation of Electrostatic Products

Product	Weight	Analyses			Distribution		
		Fe	SiO_2	Mg Alloy*	Fe	SiO_2	Mg Alloy
	%	%	%	%	%	%	%
1. Low-intensity (mag.)	9.9	35.00	9.24	55.76	15.7	7.1	8.4
1. High-intensity (mag.)	2.5	14.40	15.00	70.60	1.6	2.9	2.7
1. Nonmagnetic	43.0	0.05	1.40	98.55	0.1	4.6	64.4
2. Low-intensity (mag.)	4.8	77.00	12.30	10.70	16.0	4.4	0.8
2. High-intensity (mag.)	0.7	12.80	25.40	61.80	0.4	1.4	0.6
2. Nonmagnetic	6.7	0.15	8.36	91.49	0.1	4.3	9.3
3. Not treated	32.6	45.00	30.00	25.00	56.1	75.3	13.8
Composite	100.0	21.26	12.97	65.77	100.0	100.0	100.0

* By difference.

Air Table Separation Tests

In order to test the air table for the separation of magnesium sawdust a composite sample of magnesium sawdust was screened to several sizes. The sample used for these air-table tests was a portion of the sample on which the previously reported static and magnetic tests were made. The plus 8-mesh fraction was rejected because of size and locked particles of silica, and the minus 65-mesh was not treated because of the fineness of the material as well as the high iron and silica content of this fraction. The remaining fractions, that represented 82 percent of the original weight, were tabled individually. A cleaned product that analyzed 0.06 percent iron and 2.3 percent silica was obtained as shown in table 17.

The air-table separation was successful in removing the bulk of the iron - all the magnetic iron shot - in the sample, but as was expected, the removal of silica was not very efficient. It is possible that more of the silica could be removed by more careful adjustment of the table, but observations made during the table tests indicated that the air table would be employed most satisfactorily as a roughing machine to remove iron and possibly 75 percent of the sand ahead of the electrostatic separator, which does not remove iron.

The data of table 17 show that it was possible to make a concentrate that contains 0.06 percent iron, 2.27 percent sand, and 97.67 percent "H" alloy; this concentrate contained only 45 percent of the magnesium alloy in the original sample. The silica content of the air table concentrate is too high for efficient melting. The recovery of only 45 percent of the magnesium alloy from a head sample that contained 85 percent magnesium alloy is not satisfactory. Engineering assumptions were made:

Table 17. - Air Table Separation of Magnesium Sawdust.

Product		Analyses				Distribution		
Mesh Tyler	Description	Weight %	Fe %	SiO_2 %	Alloy* %	Fe %	SiO_2 %	Alloy %
+8	Not treated	7.5	0.20	15.00	84.80	0.08	6.3	10.0
-8-,+14	Concentrate	1.9	0.06	2.96	96.98	0.01	0.3	2.9
-8-,+14	Tailing	4.2	0.19	21.00	78.81	0.06	5.0	5.2
-14-,+20	Concentrate	7.9	0.05	0.93	99.02	0.24	0.4	12.4
-14-,+20	Tailing	4.0	19.10	15.00	65.90	4.01	3.4	4.2
-20-,+65	Concentrate	19.2	0.06	2.77	97.17	0.06	3.0	29.7
-20-,+65	Middling	10.2	1.42	22.80	75.78	0.74	13.1	12.2
-20-,+65	Tailing	54.5	44.40	21.20	34.40	79.80	41.4	18.8
-65-,+100	Not treated	6.8	30.70	44.10	25.20	10.97	16.9	2.7
-100-,	Not treated	3.8	20.30	47.50	32.20	4.03	10.2	1.9
	Composite	100.0	19.00	17.70	63.30	100.00	100.0	100.0
	Comp. Conce.	29.0	0.06	2.27	97.67	0.31	3.7	45.0

* Analyses by difference.

1. The middling may be retreated and approximately 67 percent of the alloy recovered as concentrate, and 33 percent of the alloy combined with the original tailing fractions.

2. The total tailings may be retreated and 50 percent of the magnesium alloy in the tailings recovered in the concentrate, while 50 percent is rejected in the final tailing.

If these assumptions were true, 70 percent of the magnesium alloy in the raw sawdust could be recovered in a concentrate that contains 2.27 percent silica and 0.06 percent iron.

Final Pilot Plant Beneficiation Tests on Representative Samples

Examination, Chemical and Microscopic Characteristics

The work reported in prior sections of this paper was conducted on several grab samples of magnesium sawdust produced at the Maryland Sanitary Manufacturing Corporation. Before the war Maryland Sanitary manufactured ceramic-enameled, cast-iron, bathroom fixtures and was converted to a magnesium airplane parts foundry by the War Production Board. Consequently, all of the practices at this foundry may not be the same as those of some of the older magnesium foundries set up in conjunction with primary magnesium production. For this reason a 1,000-pound sample of magnesium sawdust was collected at the Teterboro, New Jersey, foundry of the Eclipse-Pioneer Division of the Bendix Aviation Corporation for comparative tests on electrostatic and air tabling beneficiation methods.

This sample collected at the Bendix foundry was different from all previous samples; no metallic iron shot were noted and the sample contained considerably more casting sand. All of the sand grains were stained with carbon; whereas, the sand grains separated from the previous samples were white and were not stained. It was thought that possibly the Bendix foundry

used baked-sand-moulds rather than green sand, because the carbon stain on the sand could have been produced by decomposition of oil and organic binders. However, further investigation showed that this was a normal green-sand-mould, baked-core foundry and that some used core sand was being mixed with moulding sand and the mixture subsequently retempered for use as moulding sand. The magnesium alloy particles were free from contaminating material, except in the coarsest size, and the bulk of the alloy grains were found in the -14-,-65-mesh fraction. The microscopic characteristics of each individual size fraction of the sample are described in table 18.

Chemical analyses were made on the several screen fractions of the magnesium sawdust, and the plus 8-mesh fraction was carefully hand-sorted to remove tramp iron. The results of these analyses are listed in table 19. Very careful chemical analyses were made on the screen fractions and on beneficiated sawdust which determined the composition of the magnesium alloy. A comparison of the results of these analyses and the stipulations of Aeronautical Material Specification 4420 is given in table 20. All impurities, that could be detected, spectrographically, are listed in the table.

The screen analysis of the head sample with chemical analyses of each size fraction is given in table 21. This table shows that simple screening on 14- and 28-mesh screens will segregate over 55 percent of the magnesium alloy in the sample into a high-grade concentrate analyzing 98.98 percent magnesium alloy.

Table 18. - Microscopic Examination of Head Sample Screen Fractions of Magnesium Sawdust from the Bendix Aviation Corporation

Mesh Size	Description
+8	Irregular-shaped metal particles, fragments of wood, wire straw, and clusters of oil stained sand particles.
-8-,+14	Mainly magnesium alloy sawdust with small amounts of wood and oilstained sand
-14-,+20	Mainly magnesium alloy sawdust with less wood but more sand than coarser sizes.
-20-,+28	Mainly magnesium alloy sawdust with small amount of sand.
-28-,+35	About 95 percent magnesium alloy and 5 percent sand.
-35-,+48	About 90 percent magnesium alloy and 10 percent sand.
-48-,+65	About 50 percent sand and remainder mainly magnesium alloy.
-65-,+100	About 85 percent sand and remainder mainly magnesium alloy.
-100-,+200	Mainly sand.
-200-	Very small amount of magnesium alloy.

Table 19 - Analysis of Magnesium Sawdust Head Sample from the Bendix Aviation Corporation

Determined	Percent
Magnesium alloy	63.10
Tramp iron	0.42
Insoluble, dried at 110° C.	36.48
Insoluble, ignited at 600° C.	36.06
Organic insoluble	0.42

Table 20. - Comparison Magnesium Alloy from Bendix Aviation Magnesium Sawdust and A.M.S. 4420

Determined	Bendix Percent	A.M.S. 4420 Percent
Aluminum	6.09	5.3 to 6.7
Zinc	2.86	2.5 to 3.5
Manganese	0.21	0.15 minimum
Silicon	0.05	0.30 maximum
Copper	0.01	0.05 maximum
Nickel	nil	0.01 maximum
Total Other Impurities	0.08	0.30 maximum
Iron	0.08	---
Magnesium	90.08	remainder

Table 21. - Screen Analysis of Magnesium Sawdust from Bendix Aviation Corporation

Mesh Size	Fraction Weight	Analyses				Distribution Mg. Alloy
		Insol. 110°C.	Insol. 600°C.	Unalloyed Fe	Mg Alloy	
Tyler	%	%	%	%	%	%
+8	2.1	53.90	53.01	7.40	38.70	1.27
-8-,+14	2.7	7.90	7.11	0.10	92.00	3.90
-14-,+20	8.6	0.99	0.87	0.05	98.96	13.34
-20-,+28	27.1	1.01	0.94	0.01	98.98	42.05
-28-,+35	9.8	5.08	4.97	0.07	94.85	14.57
-35-,+48	15.7	33.40	32.10	0.13	66.47	16.36
-48-,+65	16.1	76.60	75.90	0.16	23.34	5.89
-65-,+100	8.0	95.90	90.80	0.16	3.94	0.49
-100-,+150	4.9	88.00	87.10	0.21	11.79	0.92
-150-,+200	2.6	86.30	84.90	0.45	13.25	0.52
-200-,	2.5	81.40	75.50	1.04	17.56	0.69
Composite	100.0	35.94	34.92		63.76	100.00

Air Table Separation

The +8-mesh fraction of the magnesium sawdust comprised only 2.1 percent by weight of the total sample received and contained only 1.27 percent of the magnesium alloy. This fraction consisted of irregularly shaped pieces of magnesium casting alloy, tramp iron, wood, straws, and clusters of oil-stained sand. The small amount of this material would not warrant any continuous recovery process, but if allowed to accumulate, it may be treated periodically by using grinding and screening methods to remove the sand and a magnet to remove the tramp iron. Laboratory tests on grinding, hand-sorting, and magnetic separation resulted in the recovery of 39.5 percent by weight of this fraction in a concentrate containing 95 percent magnesium metal. This represents a recovery of only 0.8 percent of the original sample, or 1.22 percent of the magnesium alloy in the head sample. The 95 percent grade alloy melts with difficulty because of reaction between magnesium and silica; the production of a higher-grade concentrate from this fraction was not possible because of interlocked metal-sand particles.

The -8-,+65-mesh fraction of the magnesium sawdust was examined by treatment with a Davis Tube magnetic separator in order to determine the amount of magnetic iron in the sawdust. The magnetic material separated amounted to 0.13 percent of the weight of the sample and consisted of magnetic iron oxide similar to mill scale. No metallic iron was observed in this magnetic concentrate. The separation of this small amount of impurity from the alloy would not justify treatment on any commercial magnetic separator.

Previously reported tests had indicated that the air table could probably be used to separate magnesium alloy from sand if the feed to the table was closely sized. For the tests reported on herein, the +8-mesh and the -65-mesh fractions were not treated and the -8-,+65-mesh fraction was sized on 14-, 20-, and 35-mesh screens prior to tabling. Each of these closely sized fractions was treated separately and a concentrate, a middling, and a tailing produced. Because each middling fraction was a mechanical mixture of separate particles of sand and magnesium alloy, which would normally be returned to the table for retreatment, the final results of the tests were calculated so that the middlings were distributed in the proper proportion between the concentrate and tailings.

The results of the air-tabling test, shown in table 22, indicate that 58.16 percent by weight of the original sawdust was recovered in a concentrate that contained 98.71 percent magnesium alloy, 0.15 percent unalloyed iron, and 1.00 percent insoluble. In this test 92.6 percent of the magnesium alloy in the original sample was recovered in the concentrate.

Electrostatic Separation

A portion of the same -8-,+65-mesh magnesium sawdust used for air table beneficiation tests was used for tests of electrostatic separation. The first series of experiments using an electrostatic separator with negatively-charged, low-pressure, helium-tube, sparkless electrodes was not considered satisfactory because the grade of product as well as the percent recovery was low. The second series of experiments using an electrostatic separator equipped with conventional, negatively-charged, metallic electrodes was highly satisfactory. In these tests a high-intensity twelve-roll separator arranged in four units of three rolls

Table 22. - Air Table Separation of Magnesium Sawdust from the Bendix Aviation Company.

Product	Fraction Weight	Chemical Analyses				Distribution			
		Mg Alloy	Unalloyed Iron	Insoluble 110°C.	Insoluble 600°C.	Mg Alloy	Unalloyed Iron	Insoluble 110°C.	Insoluble 600°C.
	%	%	%	%	%	%	%	%	%
Heads	100.00	63.10	0.42	36.48	36.06	----	----	----	----
Table Concs.	58.16	98.71	0.15	1.14	1.00	92.6	18.8	1.8	1.6
Table Tails	27.74	8.53	0.32	91.35	91.15	3.7	19.2	67.5	67.9
-8-mesh	3.50	38.70	7.40	53.90	53.00	2.2	55.9	5.0	5.0
-65-mesh	10.60	8.93	0.27	90.80	89.40	1.5	6.1	25.7	25.5
Composite	100.00	62.02*	0.46*	37.52*	37.19*	100.0	100.0	100.0	100.0

* Calculated Analyses for Comparison with Head Analyses.

each was used. The first unit of three rolls treated the heads and produced a rougher concentrate that was circulated to the third unit, and a rougher tailing that was circulated to the second unit. The second unit operated as the first scavenger concentrator and produced a finished tailing and a first scavenger concentrate that was circulated to the fourth unit. The third unit operated as a cleaner and produced the final concentrate and a cleaner tailing that was circulated to the fourth unit. The fourth unit operated as a second scavenger concentrator and produced a final tailing that was combined with the first scavenger tailing, from the second unit, and a second scavenger concentrate that was circulated to the third or cleaner unit for retreatment.

Statistical data on the analyses and weights of all intermediates and final products made during the electrostatic separation of magnesium sawdust are presented in table 23.

The results of cleaning magnesium sawdust by a combined screening and static separation method are given in table 24.

The data of table 24 prove that it was possible to concentrate a magnesium sawdust analyzing, 65.58 percent alloy, 0.32 percent unalloyed iron, 30.58 percent siliceous insoluble, and 0.62 percent organic insoluble by a combined screening and electrostatic method and produce a concentrate analyzing 98.4 percent alloy, 0.28 percent unalloyed iron, 0.55 percent siliceous insoluble and 0.56 percent organic insoluble. The process recovered 93.3 percent of the magnesium alloy in the original head sample.

Comparison of Air Table and Static Concentration Methods.

The tests reported on in the two sections immediately preceding this show that there were no appreciable differences in grade of concentrates

Table 25. - Chemical Analyses of Intermediates and Products in a Test of Electrostatic Separation of Magnesium Sawdust from the Bendix Aviation Corporation

Product	Source	Fraction Weight	Chemical Analyses			
			Mg Alloy	Unalloyed Iron	Insoluble	
					110°C.	600°C.
Description	Unit	%	%	%	%	%
Raw Sawdust						
Heads		100.00	68.58	0.32	31.10	30.58
Composite		100.00	67.16	0.55	32.09	31.34
+8-Mesh	Screens	3.50	38.70	7.40	53.90	53.00
-65-Mesh	Screens	10.60	8.93	0.27	90.80	89.40
+8-,-65-Mesh heads	Static Rougher	85.90	77.16	0.04	22.80	22.40
Concentrate	Static Rougher	62.53	96.50	0.31	3.32	2.59
Tailing	Static Rougher	23.37	17.80	0.42	81.80	80.80
Heads	First Scavenger	23.37	17.80	0.42	81.80	80.80
Concentrate	First Scavenger	7.38	50.20	0.08	49.70	49.20
Tailing	First Scavenger	15.99	4.60	0.47	94.90	93.90
Heads	Static Cleaner	68.11	96.30	0.29	3.44	2.78
Concentrate	Static Cleaner	63.68	98.40	0.28	1.01	0.55
Tailing	Static Cleaner	4.43	69.40	0.00	30.60	29.90
Heads	Second Scavenger	11.82	57.60	0.05	42.50	42.00
Concentrate	Second Scavenger	5.58	94.00	0.00	5.88	4.84
Tailing	Second Scavenger	6.24	23.40	0.13	76.40	74.60
Final Concentrate	Static Cleaner	63.68	98.40	0.28	1.01	0.55
Final Tailing	Static Scavengers	22.22	9.89	0.38	87.73	88.44

Table 24. - Electrostatic Separation of Magnesium Sawdust from the Bendix Aviation Company

Products	Fraction Weight	Chemical Analyses				Distribution			
		Mg Alloy	Unalloyed Iron	Insoluble		Mg Alloy	Unalloyed Iron	Insoluble	
				110°C.	600°C.			110°C.	600°C.
	%	%	%	%	%	%	%	%	%
Heads	100.00	65.68	0.32	31.10	30.58	---	---	---	---
Static Conc.	63.68	98.40	0.28	1.10	0.55	93.30	32.73	1.99	1.12
Static Tail	22.22	9.89	0.38	39.73	38.44	3.28	14.65	52.14	52.70
-8-Mesh	3.50	38.70	7.40	53.90	53.00	2.01	47.27	5.89	5.93
-65-Mesh	10.60	6.93	0.27	90.80	89.40	1.41	5.49	29.98	30.25
Composite	100.00	67.16*	0.55*	32.09*	31.24	100.00	100.00	100.00	100.00

* Calculated Analyses for Comparison with Head Analyses.

or recovery of magnesium in the concentrates produced, by the separation of sawdust with either air table or static methods. Data showing the similar results of these two different methods of concentration are given in table 25.

As the results obtained are for all practical purposes identical, the air table method would be more practicable for commercial utilization because a standard air table would be satisfactory; whereas an especially designed electrostatic separator would be required. Any operator familiar with milling operations could operate the air table, but the operator of an electrostatic separator would require considerable training.

Comparative Examination of Several Magnesium Sawdusts

Screen and microscopic examination of magnesium sawdust from both the Maryland Sanitary Manufacturing Corporation and the Bendix Aviation Corporation could be correlated roughly with chemical analyses of these materials. In addition it was noticed that the -8-mesh sawdust contained no looked grains of metal and insoluble. Apparently the amenability of magnesium sawdust to air table beneficiation could be evaluated by microscopic examination of screened samples. In order to test this hypothesis, samples of sawdust were taken from magnesium foundries at the Ford Motor Company, River Rouge Plant and the Dow Chemical Company, Bay City Plant. Table 26 gives the results of a microscopic examination of the Ford sample and table 27 the results of an examination of the Dow sample. Table 28 lists screen analyses, chemical analyses for siliceous insoluble, and microscopic estimates of the siliceous insoluble for samples of sawdust from Bendix, Ford and Dow foundries.

Table 25. - Comparison of Air Table and Static Methods for the Separation of Magnesium Sawdust.

Concentration Method	Recovery of Mg Alloy %	Concentrate Analyses			
		Mg Alloy %	Unalloyed Iron %	Insoluble Organic %	Insoluble SiO_2 %
Electrostatic	95.90	98.40	0.28	0.58	0.65
Air Table	92.60	98.71	0.15	0.14	1.00

Table 26. - Microscopic Examination of a Magnesium Sawdust Sample from the Ford Motor Company, River Rouge Plant

Mesh Size Tyler	Description
+8-	Predominantly sawdust and pieces of castings with lesser amounts of wood splinters, paper, brush bristles, wire and pieces of tobacco.
-8-, +10-	Predominantly sawdust; small amounts of paper and pieces of wood.
-10-, +14-	Predominantly sawdust; small amounts of paper and pieces of wood.
-14-, +20-	Predominantly sawdust; small amounts of paper and pieces of wood.
-20-, +28-	Predominantly sawdust; small amounts of paper and pieces of wood.
-28-, +35-	Predominantly sawdust; a few quartz grains, some clean and some oil stained.
-35-, +48-	Predominantly sawdust; 1-5 percent quartz grains, some clean and some oil stained.
-48-, +65-	Predominantly sawdust; 1-5 percent quartz grains, some clean and some oil stained.
-65-, +100-	Predominantly sawdust; 1-5 percent quartz grains, some clean and some oil stained.
-100-, +200-	Predominantly sawdust; 20-25 percent quartz grains, some clean and some oil stained.
-200-,	Predominantly sawdust; 20-25 percent quartz grains, some clean and some oil stained.

Table 27. - Microscopic Examination of a Magnesium Sawdust Sample from the Dow Chemical Company, Bay City Plant.

Mesh Size Tyler	Description
+8-	Predominantly sawdust and large pieces of casting with lesser amounts of large oil stained quartz aggregates, baling wire, tobacco and a cigarette stub.
-8-, +10-	Predominantly sawdust with several oil stained quartz aggregates.
-10-, +14-	Predominantly sawdust with several oil stained quartz aggregates and several pieces of wood.
-14-, +20-	Predominantly sawdust, several oil stained quartz aggregates.
-20-, +28-	Predominantly sawdust, few discrete grains of oil stained quartz.
-28-, +35-	Predominantly sawdust, 1-5 percent oil stained quartz.
-35-, +48-	Predominantly sawdust, 1-5 percent oil stained quartz.
-28-, +65-	Predominantly sawdust, 20-25 percent oil stained quartz.
-65-, +100-	Predominantly sawdust, 20-25 percent oil stained quartz.
-100-, +200-	Predominantly sawdust, < 25 percent quartz.
-200-,	Predominantly sawdust, < 25 percent quartz.

Table 28. - Characteristics of Three Samples of Magnesium Sawdust

Mesh Size		Weight			Chemical Analyses Siliceous Insoluble			Microscopic Estimate Siliceous Insoluble		
Tyler		Bendix %	Ford %	Dow %	Bendix %	Ford %	Dow %	Bendix %	Ford %	Dow %
	+8-	2.1	5.07	3.40	55.01	-	-	-	-	-
-8-,	+10-	1.7	12.71	0.20	7.11	0.42	2.59	-	<1	1-5
-10-,	+14-	1.0	21.27	2.47	7.11	0.44	0.27	-	<1	<1
-14-,	+20-	3.6	24.91	28.20	0.87	0.58	0.19	-	<1	<1
-20-,	+28-	27.1	11.85	21.47	0.94	1.06	0.42	-	<1	<1
-28-,	+35-	9.5	8.64	26.46	4.97	2.29	1.22	5.0	1-5	1-5
-35-,	+48-	15.7	8.49	10.13	32.10	3.71	5.24	10.0	1-5	1-5
-48-,	+65-	16.1	3.78	4.26	75.90	5.74	17.3	50	1-5	20-25
-65-,	+100-	8.0	1.78	2.22	90.80	5.21	27.2	85	1-5	20-25
-100-,	+200-	7.4	1.36	1.01	86.70	14.0	24.9	>85	20-25	>25
-200-,		2.5	0.14	0.19	75.80	30.4	18.2	>85	20-25	>25

The data of tables 26 and 28 show that it was possible to estimate the silica content of magnesium sawdust by microscopic methods. It was also possible to determine degree of freedom and hence amenability to air table beneficiation.

Briquetting Tests on Sawdust Concentrates

The first small-scale melting tests on non-briquetted cleaned sawdust were unsuccessful because the proper flux was not available. Burning losses on melting were excessively high, being 25 to 75 percent. The use of standard Dow No. 230 flux and possibly briquetting of the melting stock should lower these burning losses to an acceptable value.

Briquetting tests were made at a series of pressures ranging from 5 to 25 tons per square inch. The resulting data are listed in table 29 and are presented graphically by the curve of figure 4. The third column of the table represents the solidity developed by pressure based on a unity value of solidity equal to a specific gravity of 1.853, the true specific gravity of the sawdust. The value 1.853 was obtained by measurements of weight and of volume by displacement.

Melting Tests on Magnesium Sawdust Concentrates

Preliminary Tests.

Preliminary melting tests were made on concentrates produced by the electrostatic beneficiation of Maryland Sanitary Manufacturing Corporation magnesium sawdust that had been briquetted. The briquettes were made at a pressure of 10 tons per square inch for use in these melting tests. Melts were made by submerging briquettes under a molten heel of standard, Dow No. 310, refining flux. As this flux is designed to thicken rapidly on being held above its melting point the operation was somewhat difficult

Table 29 - Results of Briquetting Tests on Cleaned Magnesium Sawdust from Maryland Sanitary Manufacturing Corporation

Pressure Tons/sq.in.	Specific Gravity	Solidity Developed Sp. G/1.855	Remarks
-	1.855	1.000	Displacement Sp. G. of Sawdust
0	0.264	0.145	
2.76	0.855	0.462	Soft. Will not withstand handling.
2.76	0.787	0.425	
5.52	1.045	0.564	Fragile
5.52	1.075	0.585	
8.28	1.190	0.645	Fragile
8.28	1.212	0.654	
11.05	1.226	0.661	Will withstand handling.
11.05	1.207	0.651	
13.82	1.342	0.725	
13.82	1.348	0.727	
16.87	1.412	0.762	Well compressed - strong.
16.57	1.408	0.758	
19.34	1.445	0.780	
19.34	1.452	0.783	
22.10	1.482	0.799	
22.10	1.465	0.790	
22.10	1.494	0.806	

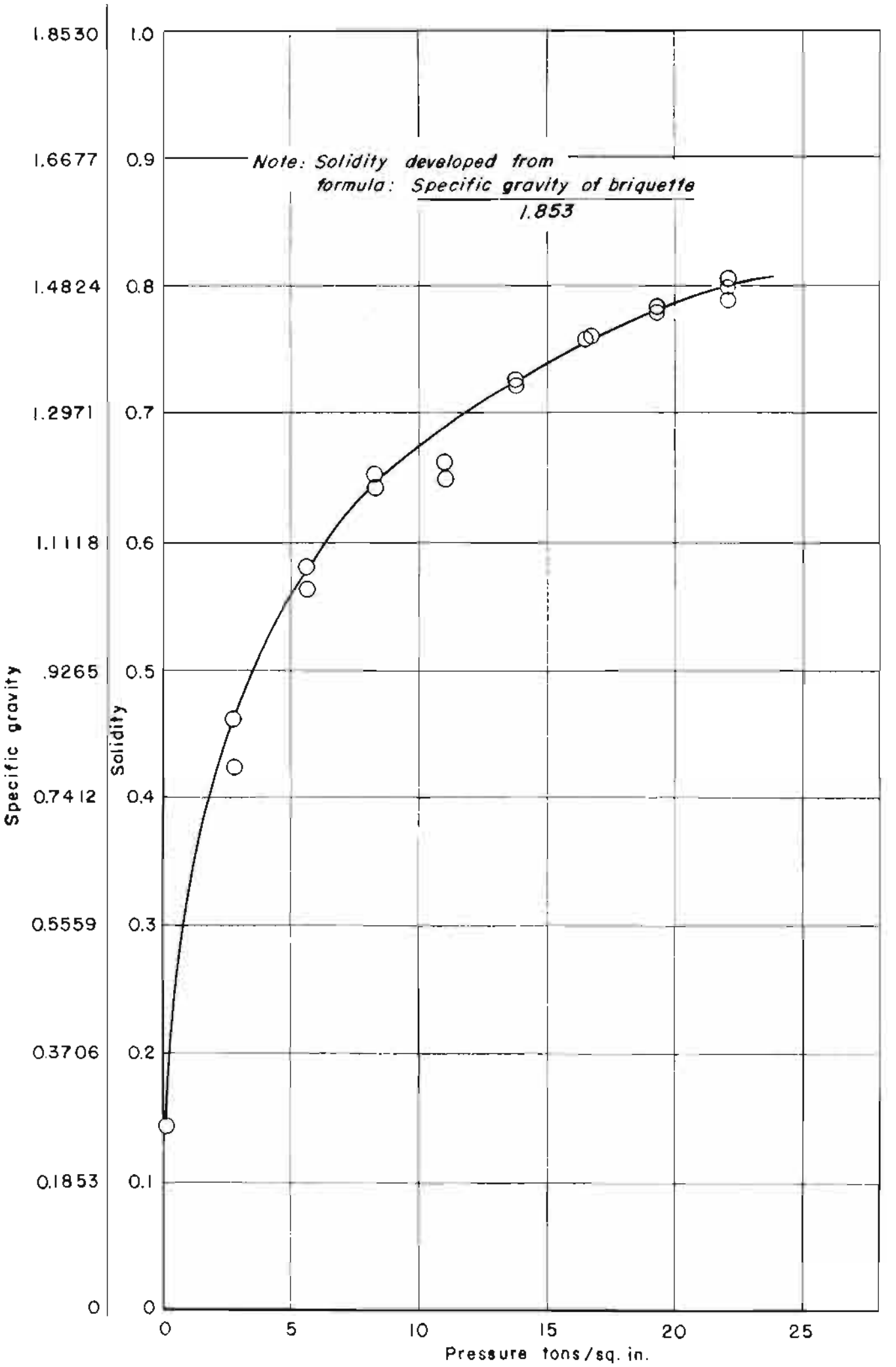


Figure 4 – RESULTS OF BRIQUETTING TESTS

and the melting period had to be reduced to as short a time as possible. Burning losses on melting were 7.5 percent. The cast metal weighed 92.5 percent of the briquette weight charged. Analyses comparing the cast metal with raw and cleaned sawdust and with Aeronautical Material Specification 4420 are listed in table 30. No attempt to refine the cast metal was made. The high iron value listed would be lowered to a value under the specification limit by the standard refining method using a flux containing manganese chloride.

Loss of Metal on Melting by Silica-Magnesium Reactions.

Additional melting tests on magnesium sawdust from the Maryland Sanitary Manufacturing Corporation were made to determine the mechanics of the reactions that may occur on melting. Magnesium is oxidized to MgO by silica at temperatures near the melting point of the metal. Melts were made on loose cleaned sawdust, on partly cleaned sawdust and on dirty sawdust. In these melts the pasty method of melting was employed because this method consumes less flux and inhibits reaction between magnesium and silica. The data obtained during the course of these preliminary experiments are listed in table 31.

The data of table 31 show that metal loss on melting was probably a direct function of the silica content of the charge and that flux consumption was also a direct function of the silica content of the charge.

Effects of Briquetting on Metal Recovery on Melting.

Further evidence of reaction between silica and magnesium was obtained by comparative melting experiments on dirty briquetted sawdust and dirty nonbriquetted sawdust. Briquetting dirty sawdust before melting should hold the silica in contact with the magnesium until the metal was thoroughly liquid, thus allowing maximum chance for reaction.

Table 30. - Comparative Analyses Magnesium Sawdust Products

Determined	Product			
	Raw Sawdust %	Cleaned Sawdust %	Cast Metal %	AMS 4420 %
Al	4.45	5.85	5.47	5.3 to 6.7
Zn	2.22	2.98	2.83	2.5 to 3.5
Mg*	70.00	90.00	88.50	Remainder
Mn	0.16	0.19	0.21	0.15 Minimum
Cu	0.09	0.04	0.03	0.05 Maximum
Ni	nil	nil	nil	0.01 Maximum
Si	0.08	0.16	0.24	0.30 Maximum
Fe	0.12	0.08	0.07	0.03 Maximum
Magnetic Fe	7.53	nil	-	-
Sand	15.20	0.65	-	-
Others	-	-	-	0.30 Maximum
Total	99.85	99.91	97.35	100.00

* All Mg analyses subject to error of ± 3%.

Table 31. - Effect of Silica on Loss on Melting and on Flux Consumption.

Sawdust Charged		Flux Used		Ingot Poured	
Weight gms	Insoluble %	Weight gms	Weight %	Weight gms	Recovery %
1,780	1.40	690	38.76	1,030	57.8
1,900	2.33	310	16.32	1,430	75.2
262	4.59	110	41.98	130	49.7
437	5.91	200	45.77	230	52.6
7,260	18.00	4,850	66.80	1,720	23.7

Data on these experiments are listed in table 32.

It was thought that briquetting of clean sawdust before melting would increase metal recovery greatly, because briquettes are not as susceptible to oxidation as loose sawdust and, in addition, may be more easily forced under the surface of molten flux. Data on comparative tests showing a gain in metal recovery on melting due to briquetting are given in table 33.

Further Studies on Metal Loss by Silica-Magnesium Reactions.

The experiments described in tables 31 to 33 yielded indicative preliminary information on the recovery on melting of magnesium sawdust. Complete and more carefully conducted experiments were performed on air-table concentrates produced from the 1,000-pound magnesium sawdust sample collected at the Teterboro, New Jersey, Foundry of the Bendix Aviation Corporation. For use in the comprehensive melting tests, three different sizes of air-table concentrates were blended so as to yield melting stock representative of the original raw sawdust. The proportion used for blending was -8-,-14+mesh 25 percent, -14-,+20-mesh 30 percent, and -20-,+35-mesh 45 percent. None of the -35-,+65-mesh concentrates were used for making up the melting stock because of the high silica content of this concentrate. The blended concentrates contained 0.68 percent insoluble.

The cleaned and blended magnesium sawdust concentrates were split into two portions, and used for comparative melting tests on loose, and briquetted sawdust. During the melting tests the insoluble content of the sawdust was systematically increased by weighed additions of silica sand so that the effect of silica on loss of metal on melting could be

Table 32. - Effect of Briquetting Dirty Sawdust Before Melting.

Charge Description	Sawdust Charged		Ingot Poured	
	Weight gms	Insol. %	Weight gms	Recovery %
Loose	7,260	18.0	1,720	23.7
Briquettes	7,250	18.0		0.0

Table 33. - Effect of Briquetting Cleaned Sawdust Before Melting.

Charge Description	Sawdust Charged		Flux Used		Ingot Poured	
	Weight gms	Insol. %	Weight gms	Percent	Weight gms	Recovery %
Loose	1,900	2.33	310	16.32	1,430	75.2
Briquettes	9,575	0.63	1,390	14.57	9,350	97.5

evaluated. In order to prevent segregation of the silica-magnesium mixture, sand additions were made to each separate unit of 500 grams of sawdust melted or briquetted. The briquettes used in these comparative tests were one inch thick, one inch wide, and four inches long and were made at a pressure of ten tons per square inch applied to 1 x 4 inch face.

Melts of loose sawdust were made by placing enough standard Dow No. 230 melting flux in a mild steel crucible to form a shallow liquid layer or flux heel. Magnesium sawdust was rabbled into the heel until a thick pasty mass resulted. The temperature was then raised until the paste was partly liquated and then more sawdust added and worked into the pasty metal-flux heel. Additions of Dow No. 230 flux were made from time to time whenever necessary to prevent burning of the charge. No attempt was made to schedule flux additions or to use any predetermined quantity of flux; the furnace operator used the minimum quantity of flux needed to prevent fires in the crucible. After all the sawdust or sawdust-sand mixture had been charged the temperature was increased to 1400° - 1450° F. for pouring; during this period the charge was periodically stirred and flux additions were made whenever burning started. Dross formed by reaction between silica and magnesium was removed by skimming during this heating period and during a holding period immediately following.

The effect of the siliceous insoluble could be seen during the melting operation as characteristic bright, reddish, glowing spots and fires on the surface and just below the surface of the melt. These fires caused by the reactions: $SiO_2+2Mg \rightarrow 2MgO+Si$, and $Si+O_2 \rightarrow SiO_2$, had

an appearance decidedly different from the characteristic white flame produced by the normal burning of magnesium in air. These local silica-caused fires could not be extinguished readily with flux but could be removed easily by skimming.

Results of this experimental study on the effect of silica on loss of metal by burning on melting are listed in table 34. Plots of both metal recovery and flux consumption against percent insoluble in the charge yielded straight lines. It was noted that more magnesium was lost by burning than the stoichiometric quantity indicated by the equation: $2Mg+SiO_2 \rightarrow 2MgO+Si$, because the silicon formed by the reaction was carried to the surface of the melt by convection currents, the flux film was ruptured by the heat of reaction, and the silicon was reoxidized to silica by oxygen from the air. These losses were intensified by the inclusion of metallic magnesium in the dross formed by reaction between silica and magnesium.

In each of the tests in table 34, the indicated quantity of 0.68 percent insoluble-containing sawdust was charged to the crucible. Prior to charging, additional sand was mixed with the sawdust so that the insoluble contents of the mixtures were fixed at the values tabulated.

Melts of briquetted sawdust were made using as melting stock a standard 1 x 1 x 4 inch briquette formed at a pressure of 10 tons per square inch. The effect of silica on loss by burning on melting was evaluated by mixing weighed quantities of sand with the magnesium sawdust before briquetting. All these melts were made in the flat-bottomed, cylindrical, mild-steel crucible that had been used for melting loose sawdust. The melts were made by starting with a 200-gram, molten, No. 230,

Table 34. - Effect of Silica on Loss by Burning on Melting Loose Magnesium Sawdust from the Bendix Aviation Corporation

Charged		Flux Used		Ingot Poured	
Sawdust gms	Insoluble %	Weight gms	Weight %	Weight gms	Recovery %
10,000	0.68	209	2.09	8,485	84.85
7,000	1.50	183	2.61	5,435	77.64
7,000	3.00	440	6.29	4,160	59.43
7,000	5.00	660	9.43	2,470	35.29
7,000	10.00	1,230	17.57	1,570	22.40

Table 35. - Effect of Silica on Loss by Burning on Melting Briquetted Magnesium Sawdust from the Bendix Aviation Corporation

Charged		Flux Used		Ingot Poured	
Sawdust gms	Insoluble %	Weight gms	Weight %	Weight gms	Recovery %
2,045	0.68	245	11.98	1,730	84.6
2,595	1.50	225	8.68	1,870	72.1
2,570	3.00	250	9.79	1,895	73.7
2,610	5.00	255	9.80	1,415	54.2
2,570	10.00	315	13.50	815	34.4
2,410	15.00	290	12.03	270	11.2

flux heel into which the first briquettes were submerged so that they would be melted without oxidation. After the first few briquettes had been added singularly, the charging rate was increased and the briquettes were held under the surface of the molten heel with an iron rod until they were wetted with flux and had started to melt. Flux was added during the period in which briquettes were being charged, whenever necessary to extinguish fires in the melting pot. Dross was removed by skimming whenever it was not possible to control burning by flux additions. Even though some metal was lost in the dross, this loss was not so great as the loss caused by an overuse of melting flux, which sinks to the bottom of the pot entrapping considerable metal.

The results of these experimental melts of briquetted magnesium sawdust are presented in table 35. These data show that briquetting has little effect on either loss by burning on melting or on flux consumption. The melting operation, however, is much more difficult if the charge is briquetted rather than loose.

The results of table 35 can be duplicated within 5 percent, but because of a more easily controlled melting technique, the results of table 34 can be checked within 1 percent.

Recommendations for Improved Melting Methods

Tests have also been conducted that have yielded data proving the necessity of specially developed melting techniques for magnesium sawdust. In this series of experiments both loose and briquetted sawdust containing 0.68 percent insoluble were melted without rabbling or puddling using the usual foundry technique for melting ingot metal. Standard Dow No. 230 melting flux was used to minimize loss by burning.

A comparison of the standard melting method and the methods developed at the Bureau of Mines is given in table 38. The data also prove that the pasty method of melting loose sawdust was preferable to the best method developed for melting briquetted sawdust. An extrapolation of this pasty method to full plant scale should be simple, and the recoveries expected would in all probability be greater than those tabulated for small-scale tests. Another similar melting method for magnesium sawdust has not been tested because it is not possible to control properly the melting conditions in small crucible-scale melts. This method is the rabbling of magnesium sawdust into a fairly large molten metal heel, held at a temperature just high enough to melt the magnesium alloy. The charging rate for this method should be regulated so that considerable sawdust would be present in suspension in the melt at all times. During the course of charging and melting, standard melting flux would be used to control fires. The writer believes that this melting method would be the most practicable plant method for the recovery of magnesium alloy from beneficiated sawdust by melting.

Magnesium Grinding Room Sludge

General

Magnesium grinding room sludge is generated in the cleaning room where the castings are cleaned by grinding off the remainder of the gates and risers, as well as by removing surplus metal and fins and polishing certain surfaces. Both abrasive wheels and high-speed rotary files are used. All grinding and most of the filing is performed in booths equipped with grill bottoms. The dust is sucked through the grill work by suitably installed high-pressure fans, and impinges into a stream of water

Table 56. - A Comparison of Standard and Special Melting Methods for Magnesium Sawdust

Charge	Melting Methods	Flux Consumption %	Ingot Recovered %
Loose	Standard	16.4	49.0
Loose	Bureau of Mines	2.1	84.9
Briquettes	Standard	10.3	30.8
Briquettes	Bureau of Mines	12.0	84.6

circulated under the booths. Magnesium-alloy dust is settled from the thin slurry in a sump. Water from the sump is recirculated through the booth circuit by pumps; the solids are periodically removed, transferred to drums and destroyed or buried. Chemical and screen analyses of dried sludge are listed in table 37. In general the sludge is relatively clean, the only major impurity being 1.48 percent sand equivalent to 0.7 percent silicon. Extremely fine particle size, characteristic of these filings and grindings, results in a semipyrophoric material that melts with difficulty. Water must be evaporated from the grindings at low temperature in order to minimize the evolution of hydrogen and subsequent fires and explosions.

The tabulated analyses of this product shown in table 37 indicate very clean material. The fine particle size of this material and its semipyrophoric nature introduce serious difficulties on melting. However, cleaned sludge, relatively free of abrasive insoluble matter, could obviously be employed in incendiaries.

Concentration by Tabling Methods

As the sludge is always available water-wet it was decided to confine all beneficiation tests to those tests based on hydraulic methods. Floating the metal that amounted to 98 percent of the sludge away from the 1.6 percent insoluble did not seem to be a practicable method of beneficiation. Gravity methods of concentration were thought to be applicable. The results of tabling experiments are listed in table 38. During tabling the heavy abrasive particles followed the riffles and were discharged at the end of the table. The light magnesium particles ran across the riffles and were discharged from the side of the table.

Table 37. - Chemical and Screen Analyses of Magnesium Grinding Room Sludge from the Maryland Sanitary Manufacturing Corporation

Screen Analysis			Chemical Analysis	
Mesh Size Tyler	Weight %	Cumulative %	Determined	Percent
+8	0	0	Al	5.28
-8-,+20	0.76	0.76	Zn	2.70
-20-,+65	13.36	14.12	Mg*	91.60
-65-,+100	16.03	30.15	Mn	0.18
-100-,+150	21.24	51.39	Cu	0.07
-150-,+200	19.17	70.56	Ni	nil
-200-,	29.44	100.00	Si	0.11
			Fe	0.08
			Sand	1.48
			Total	101.50

* Subject to error of ± 5%.

Table 38. - Results of Tabling Tests on Magnesium Grinding Room Sludge from the Maryland Sanitary Manufacturing Corporation.

Product Designation	Weight Fraction %	Analyses HCl Insoluble %	Distribution HCl Insol. %	Distribution "H" Alloy %
Heads, Raw Sludge	100.0	1.48	100.0	100.0
Concentrates, First Grade	76.5	0.31	16.5	77.4
Concentrates, Second Grade	15.2	0.40	4.1	15.3
Concentrates, Third Grade	5.0	0.68	2.3	5.1
Middlings	1.8	7.64	0.2	1.7
Tailings	1.5	66.30	67.9	0.5
Composite, Raw Sludge	100.0	1.48	100.0	100.0
Concentrates, Combined	96.7	0.35	22.9	97.8

After all the original sludge was tabled, the usual middling fraction was retabled producing a second-grade concentrate that was kept separate, a tailing fraction that was combined with the original tailings, and a middling fraction. These second middlings were retabled, yielding a third concentrate fraction, the listed middling fraction and a tailing fraction that was also combined with the original tailings.

Table 39 lists the critical screen analysis of the raw sludge of tables 38 and 40 before tabling.

Table 40 lists complete comparative analyses of raw sludge and the combined concentrates developed by the tests described in table 38 and also compares these analyses with the stipulations of Aeronautical Material Specification 4420. Tabling of the raw sludge brought its composition within the limits of the controlling specification.

An additional check on this method of beneficiation has also been conducted; for the purpose of this duplicate run a barrel of magnesium sludge, resulting from wet grinding on abrasive wheels, and consisting of finely divided magnesium metal associated with minute particles of abrasives from the wheels, was obtained for beneficiation tests for the removal of contaminating material by ore dressing methods. This sample had the partial chemical analysis listed in table 41 and the results of a wet screen analysis on this sample of sludge, as received are shown in table 42. The sludge was very uniform in grade with no apparent concentration of impurities in any of the screen sizes. The tabulated analyses of tables 41 and 42 do not composite to 100 percent because of this sample of sludge was coated heavily with magnesium oxide; no oxygen determinations were made.

Table 39. - Critical Screen Analysis Raw Grinding Room Sludge Solids Generated by the Maryland Sanitary Manufacturing Corporation.

Product Designation	Screen Size Tyler	Weight Fraction %	Analyses HCl Insol. %	Calc. Equiv. HCl Insol. %	Distribution HCl Insol. %
Heads, Raw Sludge	-	100.00	1.48	1.48	100.00
-	+20	0.76	3.57	0.03	2.78
-	-20-,+65	13.36	3.24	0.45	39.46
-	-65-,+100	16.03	1.23	0.10	9.17
-	-100-,+150	21.24	0.68	0.15	13.77
-	-150-,+200	19.17	0.54	0.10	9.17
-	-200-,	29.44	0.93	0.28	25.67
Composite, Raw Sludge	-	100.00	1.09	1.09	100.00

Table 40. - Comparative Analyses of Grinding Room Sludge Solids from Maryland Manufacturing Corporation

Determined	Product		
	Raw Sludge %	Concentrates %	AMS 4420 %
Al	5.25	5.34	5.5 to 6.7
Zn	2.70	2.74	2.5 to 3.5
Mg*	91.60	91.00	Remainder
Mn	0.18	0.18	0.15 Minimum
Cu	0.07	0.07	0.05 Maximum
Ni	nil	nil	0.01 Maximum
Si	0.11	0.11	0.30 Maximum
Fe	0.08	0.08	-
Sand	1.46	0.35	-
Others	-	-	0.30 Maximum
Total	101.50	99.87	100.00

* Mg analyses subject to error of ± 3%.

Table 41. - Analysis of Magnesium Sludge

Determined	Percent
Mg	83.6
Al	6.29
Zn	1.74
Mn	0.05
Fe	0.13
SiO_2	1.11
Ni	Nil
Cu	0.05
Total	91.23

Table 42. - Wet Screen Analysis on Magnesium Sludge as Received.

Mesh Size Tyler	Fraction Weight %	Chemical Mg %	Al %	Zn %	Fe %	SiO_2 %	Spectrographic Mn %	Cu %	Ni %
-20	1.5	83.7	6.65	1.98	.77	1.44	.05-.1	.1-.5	.00
-20-,-65	16.4	79.8	8.10	2.07	.29	1.28	.05-.1	.1-.5	.00
-65-,-100	25.5	85.8	5.89	1.54	.17	.56	.05-.1	.1-.5	.00
-100-,-150	24.7	85.8	5.97	1.54	.15	.53	.05-.1	.1-.5	.00
-150-,-200	17.9	84.9	5.91	1.25	.17	.58	.05-.1	.1-.5	.00
-200-,	14.2	79.2	6.46	1.64	.30	1.20	.05-.1	.1-.5	.00
Composite	100.0	83.5	6.35	1.60	.20	.70	.05-.1	.1-.5	.00
Heads	100.0	83.6	6.29	1.74	.20	1.11	.05-.1	.1-.5	.00

Mesh Size Tyler	Distribution Mg %	Al %	Zn %	Fe %	SiO_2 %
-20	1.5	1.6	1.9	5.5	3.2
-20-,-65	15.7	20.9	21.3	22.5	30.3
-65-,-100	26.0	25.1	24.4	20.5	15.2
-100-,-150	25.0	25.1	25.5	16.0	18.9
-150-,-200	18.5	16.7	14.0	15.0	9.8
-200-,	13.4	14.6	14.6	20.5	24.6
Composite	100.0	100.0	100.0	100.0	100.0

The sludge was washed on a 20-mesh screen previous to tabling, removing all coarse material that caused hindering in the previous test. The minus 20-mesh material was tabled, the magnesium metal washed over the riffles and the abrasive material along the riffles. Results of this test are shown in table 43.

After tabling the fine grindings were dried slowly in a low temperature, steam-heated cabinet. Considerable care was necessary during the drying operation because the reaction between water and metallic magnesium generates hydrogen at an appreciable rate and in addition the finely divided grindings are so easily ignitable that they may be classed as "semipyrophoric."

Attempts to Melt.

Briquettes of this dust were made at pressures up to 25 tons per square inch. In general none of the briquettes were strong enough to withstand handling because the coating of oxides on each one of the metallic particles prevented proper metal to metal contacts, and the particles were too short to interlock properly.

Melting tests on briquetted cleaned grinding room sludge have resulted in a maximum metal recovery of only 65 percent. The majority of the melting tests were not successful because enough magnesium oxide was formed by burning of the fine metal on melting, to cause the flux to thicken to the point where no metal-flux separation was possible. Many of the experimental melts were completely lost by burning of the charge. However, samples of dry sludge concentrates were submitted to the Chemical Warfare Corps through the War Production Board for possible utilization in incendiary bombs.

Table 45. - Table Test on Magnesium Sludge

Product	Fraction Weight %	Determined: Chemical Mg %	Al %	Zn %	Fe %	SiO_2 %	Spectrographic Mn %	Ni %	Cu %
+20 Metallics	1.2	86.2	6.95	1.33	0.60	.87	.05-.1	.00	.05-.1
Concs. No. 1	78.4	84.4	5.60	1.72	1.11	.17	.05-.1	.00	.05-.1
Concs. No. 2	15.1	86.5	6.20	1.96	.56	.11	.05-.1	.00	.05-.1
Concs. No. 3	7.0	87.2	5.82	2.10	.59	.12	.05-.1	.00	.05-.1
Middlings	1.5	88.7	6.14	2.10	.81	.03	.05-.1	.00	.05-.1
Tailings	1.8	21.4	31.40	1.96	8.40	2.22	.05-.1	.00	.05-.1
Composite	100.0	83.9	6.25	1.79	1.06	0.20	.05-.1	.00	.05-.1
Heads		83.6	6.29	1.74	1.11	0.20	.05-.1	.00	.05-.1

	Distribution				
+20 Metallics	1.2	1.3	0.9	0.6	5.5
Concs. No. 1	75.8	66.2	70.6	75.4	63.6
Concs. No. 2	15.6	15.5	16.6	5.0	8.5
Concs. No. 3	7.3	6.5	8.2	3.8	4.0
Middlings	1.6	1.5	1.8	1.1	0.5
Tailings	0.5	9.0	2.0	14.1	20.0
Composite	100.0	100.0	100.0	100.0	100.0

Recommendation

It is the author's opinion that these fine magnesium alloy grindings should not be processed but should be destroyed immediately by burning in accordance with the present plant practice. If fine magnesium powder is needed for incendiaries and pyrotechnics it should be especially manufactured in a plant designed and operated for this particular job. The quantities of magnesium grindings generated at even the largest foundries do not warrant the risk of processing water-wet grindings nor would the product made pay for the required capital investment, plus the operating expenses of beneficiating and drying.

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